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TRSB MICROWAVE LANDING SYSTEM DEMONSTRATION PROGRAM AT DAKAR, S--ETC(U)
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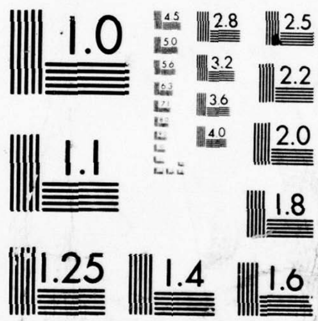

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MICROWAVE LANDING SYSTEM DEMONSTRATION PROGRAM AT DAKAR, SENEGAL

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FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington, D.C. 20590

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.

METRIC CONVERSION FACTORS

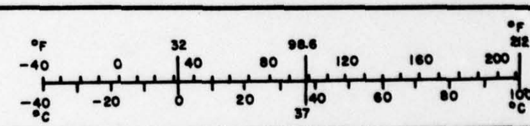
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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16. Abstract

The demonstration at Yoff Airport, Dakar, Senegal, was the eighth in a series of operational demonstrations of several TRSB system configurations at selected airports in the United States and abroad.

The TRSB Small Community System was installed on the same runway as a commissioned ILS. Flight checks established that no mutual interference resulted.

Operational demonstrations and data acquisition flights were made utilizing an FAA Boeing 727 testbed aircraft. Flight profiles included approaches, radials, and partial orbits perpendicular to the runway centerline.

Results of the operational demonstrations indicated that the performance of the TRSB Small Community System configuration was within the Phase III design requirements and met the ICAO "full capability system" requirements.

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INTRODUCTION

During the past several years, extensive engineering evaluation and flight testing has been accomplished on Time Reference Scanning Beam (TRSB) Microwave Landing System (MLS) equipments at the Federal Aviation Administration's (FAA) National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey, and at the Auxiliary Naval Landing Field, Crows Landing, California. TRSB MLS is the United States and Australian (INTERSCAN) candidate submission to the International Civil Aviation Organization (ICAO) as the future all-weather landing system to eventually replace ILS.

In March 1977, following a 15-month period of intensive and comprehensive assessment of all competing microwave landing systems, the ICAO All Weather Operations Panel (AWOP) recommended TRSB as the preferred candidate microwave landing system for international adoption. This assessment involved more than 100 leading international experts in microwave landing systems.

The Air Navigation Commission (ANC) reviewed the AWOP recommendation and forwarded it to the ICAO Council, whereupon the Council has scheduled a worldwide meeting for April 1978, to address the question of selecting the new international standard for an approach and landing system to eventually replace ILS. In the interim, in consonance with the ICAO Council suggestion that proposing States carry out system demonstration at operational airports, the FAA has developed a program to conduct operational demonstrations of several TRSB MLS hardware configurations at selected airports in the United States and abroad. (Hereafter for simplicity, "TRSB MLS" will be referred to as "TRSB.") The objectove of these demonstrations is to show that the TRSB signal format and system design are mature and satisfy the full range of requirements, from general aviation use to scheduled air carrier operations, for Category I to Category III autoland. A further objective of these demonstrations is to provide opportunities for representatives and officials of the international aviation community to gain direct knowledge of TRSB and assess its applicability to their particular requirements.

The TRSB operational and data acquisition flights of February 10 through February 16, 1978, at Yoff International Airport, Dakar, Senegal, represent the eighth in a series of operational flight demonstrations at domestic and foreign operational airports. TRSB demonstrations conducted previously are as follows:

1.	September 28-30, 1977	Cape May, N.J., USA
2.	October 31 to November 4, 1977	Buenos Aires, Argentina
3.	November 24-25, 1977	Tegucigalpa, Honduras
4.	December 5-13, 1977	JFK Airport, New York, USA
5.	January 23-24 , 1978	Kristiansand, Norway
6.	February 1-3, 1978	Brussels, Belgium
7.	February 1-3, 1978	Charleroi, Belgium

As in previous demonstrations, the TRSB demonstrations at Yoff Airport afforded area aviation officials and technical experts the opportunity to observe and participate in presentations, site tours, and actual flights in a TRSB-equipped aircraft. At Yoff Airport, Runway 01 was equipped with the TRSB Small Community System. Data flights included conventional straight-in centerline approach paths, fixed radials, descending racetrack orbits, and partial orbits.

DISCUSSION

The TRSB approach guidance equipment installed at Yoff International Airport, Dakar, Senegal, was the Small Community System manufactured by the Bendix Aviation Corporation's Communications Division in accordance with FAA specifications (see Table 1). It is representative of a simple, economical system configuration and was designed to provide azimuth proportional guidance over an area of plus and minus 10 degrees about runway centerline, with directional guidance (i. e., fly left or right) from 10 degrees out to 40 degrees similar to an ILS localizer. The elevation proportional guidance extends from 2 degrees to 15 degrees. System coverage distance is at least 20 nautical miles under heavy rain conditions, and much greater under less stringent environmental conditions. Basically, the small community TRSB was designed to provide Category I service on most runways in most airport environments. Guidance quality, however, has been shown to be considerably better than ILS Category I requirements and will support autoland operations. General information on TRSB is presented in the Appendix to this document.

Figure 1 illustrates the general plan of Yoff Airport runways including locations of the TRSB equipment serving Runway 01. Precision L-band Distance

Measuring Equipment (DME) option was not included in the Yoff Airport TRSB installation. Conventional airport VOR DME was employed for range information on all approach flights. Figure 2 diagrams both plan and elevation views of Runway 01.

System Installation

An advance team of FAA technical personnel visited Yoff Airport on December 12 to 14, 1977, and coordinated TRSB site selection, installation support requirements, and other demonstration logistics with local aviation and airport control authorities. Runway 01, having conventional instrument landing system (ILS) glide slope and localizer approach guidance facilities, was selected for the TRSB installation. This runway is 45 meters (148 feet) wide, 3490 meters (11,450 feet) long, and varies in elevation from 20 meters (66 feet) to 27 meters (87 feet) above mean sea level.

The TRSB demonstration team and Small Community System arrived at Yoff Airport aboard the FAA Boeing 727 aircraft on the afternoon of February 8, 1978. The following day, heavy moving equipment was used to unload the system from the testbed aircraft and transport it to the selected installation sites. When unloaded, the FAA aircraft conducted a pre-TRSB installation flight check of the ILS localizer. Immediately following that flight check, the TRSB system was installed. The azimuth subsystem was collocated in line with the existing ILS localizer on the Runway 01 extended centerline 17 meters (56 feet) from the overrun end as diagrammed in Figure 3. The TRSB equipment was positioned and leveled on rigid metal alloy platforms. These were securely staked to the ground with heavy steel rods. These anchor rods were driven in at approximately 25-degree angles to assure a firm and stable base for the TRSB equipments.

Following the azimuth subsystem installation, a flight check of the ILS localizer was flown to assure that any change in its performance did not exceed acceptable operational limits. Results indicated minimal affect upon ILS operation. Slight narrowing of the localizer course from 3.7 degrees to 3.5 degrees was perceived, but was within tolerance limits. The TRSB elevation subsystem was installed alongside the existing ILS glide slope structure. Its siting was 384 meters (1260 feet) from the threshold end and 122 meters (400 feet) to the left of the runway centerline (see Figure 4).

The following day (February 10), final checkout of the azimuth and elevation subsystems were accomplished. Initial flight tests were flown and tracked to assure overall system readiness.

Installation and checkout of the TRSB system was completed in less than 1-1/2 days. A 6.2 meter (20 feet) hump in the runway approximately 620 meters (2000 feet) from its stop end, complicated the line-of-sight microwave synchronization between AZ and EL sites. The problem was resolved by installing the elevation site microwave synchronization horn antenna atop the adjacent 45-foot high glide slope antenna mast. Normally, in a permanent installation, land line synchronization would be employed. Figure 5 shows this installation, and also illustrates comparative sizes, supporting structures, and real estate required for the ILS glide slope facility as opposed to the more compact and simplified TRSB elevation subsystem.

Figure 6 shows the azimuth subsystem installation sited in front of the localizer antenna array. Compared with the ILS localizer, the simplicity of the azimuth subsystem is evident in this picture. The azimuth monitor horn mast was installed at the stop end of the runway directly in front of the azimuth antenna. Power was provided by a small diesel generator at each TRSB site.

<u>TRSB Flight Path Geometry at Dakar</u>

Figure 7 depicts the straight-in approaches employed on demonstration flights. Data acquisition flight configurations were either radial flights centered upon the TRSB azimuth subsystem, or partial orbits as illustrated in Figure 8. Radial flights of 10 degrees right and left of Runway 01 centerline were made from a distance of 5 and 15 nmi at altitudes of 610 meters (2000 feet). The partial orbits were flown beyond 40 degrees right in counterclockwise direction and reversed 180 degrees through a procedure turn to complete the orbit in a clockwise direction beyond 40 degrees left of the runway centerline. An additional coverage configuration was flown in the form of a 2-nautical mile long racetrack pattern perpendicular to and 10 nmi from the threshold end of the runway, initiating at an altitude of 1.2 kilometers (4000 feet), and terminating at an altitude of 152 meters (520 feet). A series of eight clockwise racetrack patterns were flown at descending 152 kilometers (500 feet) intervals. Figure 9 illustrates this particular flight data geometry. Results indicated good TRSB signal coverage throughout the range and altitude volume of the flight.

Ground Surface Performance Tests

Due to the 6-meter (20-feet) runway hump, a runway test of azimuth signal level and coverage was made using a vehicle and the B-727 aircraft. The vehicle was equipped with an oscilloscope and angle receiver connected to a receiving horn atop a 2.4 meter (8 feet) mast. The vehicle was driven down the runway centerline away from the azimuth site. Video signal level was observed as the vehicle proceeded beyond the hump and descended below line-of-sight toward the threshold. Signal strength was found to be acceptable throughout the length of the runway. Similar favorable signal levels were observed when the B-727 aircraft taxied down the runway. Although signal strength was found to be continuous over the length of the runway, some evidence of lateral multipath reflections was observed on the oscilloscope while the test vehicle was moving down the runway in the below line-of-sight region where the multipath to direct signal ratio would be enhanced. As long as the vehicle was moving, the receiver angle output was not affected by the multipath. The video response was attributed to reflections from reinforced concrete walls 2 meters above ground and parallel to the runway along part of its length. Location of the reflecting walls in relation to the runway can be seen in Figure 1. Although some multipath was observed on the oscilloscope, no significant effects were observed during flight demonstrations.

An examination was made of the terrain topology beyond the threshold end of Runway 01 to determine the nature of possible noise reflection sources at low elevation approach angles. The runway elevation profile in Figure 2 shows that the terrain rises gradually in a dish-like form to a ridge beyond the end of the runway. Table 2 lists terrain elevation readings taken of the horizon profile ±20 degrees either side of the runway centerline.

TRSB Operational Demonstration and Data Acquisition Flights

The 48 flight runs flown during the demonstration period are listed on Table 3. All flights were tracked, although most runs were primarily for demonstration purposes. A majority of the demonstration runs were manually flown approaches leveling off and continuing over the runway at an altitude of 31 meters (100 feet). Approximately a third of these TRSB approaches were automatic-type descents designated on Table 3 as Autocoupled.

Principal aviation organizations represented were the Association for Safety of Air Navigation (ASECNA) and the African Civil Aviation Commission (AFCAC). The news media were represented by the press, radio, and

television, especially by the Senegalese Organization of Radio and Television Services (ORTS). The aircraft used on all demonstration and check flights was the FAA B-727. The aircraft was equipped to accomodate a maximum of 15 observers. Figure 10 depicts the B-727 in a typical TRSB approach prior to landing.

Weather conditions at Dakar during the TRSB demonstration period were favorable. Temperatures were normally in the range of 21°C (70°F) with clear skies and moderate winds. Table 4 provides the official daily weather breakdown during the period over which flights and tracking were performed. The weather afforded not only excellent opportunity for VFR flight conditions and passenger observation, but was also ideal for optical tracking of aircraft position.

During the primary demonstration days, ground tours of the installation sites and demonstration flights were provided. A large assembly hall near the main terminal building at Yoff Airport was the focal point for briefings. Following briefings, movies, and slides in both French and English, groups were taken on ground tours of TRSB sites and on demonstration flights.

Airborne System

The B-727 airborne TRSB system consisted of dual angle receivers, course deviation indicators, and precision DME interrogators. Instrumentation required for data acquisition consisted of a data multiplexer, digital data recorder, analog video recorder, strip chart recorder, time code generator, VHF telemetry receiver/demodulator, and a modified UHF glide slope receiver. The interrelation of the airborne TRSB system and instrumentation with the B-727 flight control system is shown in Figure 11. The data instrumentation system is pictured in Figure 12.

An omni-directional antenna mounted on the aircraft fuselage just above the center of the cockpit windshield was utilized throughout the demonstration and data acquisition activity.

Performance Assessment

Ground based tracking for the TRSB demonstrations was provided by two different types of optical tracking equipment, one located at the elevation site and one located at the azimuth site, facilitating simultaneous tracking along each axis during flights. One of the trackers was an optical electronic

tracker manufactured by British Aircraft Corporation of Australia, designed to automatically or manually track a light source on the aircraft. Angular position data were telemetered back to the aircraft on an available VHF channel. Elements of this system are depicted in Figure 13. This tracker was located 58 meters (190 feet) forward of and 15 meters (50 feet) to the left of the elevation subsystem.

The second tracking system, used to track aircraft azimuth position, was a manually operated radio-telemetry theodolite (RTT) which transmitted azimuth position data to the aircraft via a transmitter operating on an unused UHF glide slope channel. This tracking system was located along the extended runway centerline beneath the azimuth subsystem enclosure. The system is functionally depicted in Figure 14.

In the aircraft, the received tracker angle data (azimuth and elevation) was subtracted from the TRSB azimuth and elevation angle data to provide a measure of system error. In each case (azimuth and elevation), the angle difference as well as tracker angle and TRSB angle were recorded on light sensitive strip chart recorder paper. Additionally, airborne received angle data from the optical electronic tracker in digital format was recorded together with TRSB digital angle data and time code data on a digital recorder to facilitate greater flexibility in data processing and analysis at NAFEC as required.

Figures 15 through 19 are data from airborne strip chart recordings of five runs conducted between February 10, and February 15, 1978. Each of these figures contains a reproduced trace of aircraft tracked angle, TRSB receiver angle, and error between the two, for both the elevation and azimuth axes. In the data plots, small alignment bias errors have been taken out. The longitudinal axis of these plots represents range from runway threshold as determined by the airport's commissioned DME. ICAO (AWOP) total error limit boundaries for a "full capability system" configuration have been included on the figures as shown. The data presents a mix of manual and autocoupled straight-in approaches on elevation angles of 3 degrees, 3.5 degrees, and 4 degrees.

A review of the data acquired on the TRSB Small Community System shows it to be within its Phase III design requirements as well as the more stringent ICAO "full capability system" requirements.

SUMMARY OF RESULTS

The TRSB system discussed in this document is representative of a simple, economical configuration of TRSB hardware referred to as the "Small Community System." In addition to its economical system architecture, the information presented herein indicates:

1. The guidance signal quality of the TRSB system was within ICAO(AWOP) requirements for a "full capability system."

2. The TRSB "Small Community System" exceeds its performance design specifications.

3. The TRSB system can be used on the same runway as ILS without degradation of ILS performance.

4. The TRSB system required minimal site preparation and installation time.

Descriptive presentations, tours, and flight demonstrations were given to 134 visitors.

TABLE 1.
TRSB ACCURACY, PHASE III SYSTEMS

			BIAS (DEG.)	PATH FOLLOWING NOISE (DEG.)	PATH FOLLOWING ERROR (DEG.)	CONTROL MOTION NOISE (DEG.)	REMARKS
Basic Narrow	AZ	SPEC	.19	.08	.2	.07	at 50' on 2.5° G/S
	EL	SPEC	.08	.09	.12	.05	
Small Community	AZ	SPEC	.29	.15	.33	.10	at 150' on 2.5° G/S
	EL	SPEC	.11	.12	.16	.10	

NOTES ON TRSB ALLOWABLE PFE DEGRADATIONS (PHASE III CONTRACTS)

	PFE Degradation W/Distance	W/Azimuth Angle	W/Elevation Angle
Basic Narrow			
Azimuth	None	Linearly to twice C/L error at $\pm 60°$	None to 9°. Linearly to 2 times from 9° to 20°
Elevation	Linearly to 1.5 times at 20 NM	None	Linearly to 3 times from 2.5° to 20°
Small Community			
Azimuth	Linearly to 0.4° at 20 NM	Linearly to twice C/L error at $\pm 60°$	None to 9°. Linearly to 2 times from 9° to 15°
Elevation	Linearly to 1.5 times at 20 NM	None	Linearly to 3 times from 2.5° tc 15°

TABLE 2

HORIZON PROFILE SURVEY OF TERRAIN BEYOND THRESHOLD END OF RUNWAY 01, ±20° EITHER SIDE OF CENTERLINE

ALACS - Degrees/Offset			ALACS + Degrees/Offset		
℄	+0.61°		℄	+0.61	
1°	+0.70		1°	+0.67	
2°	+0.70		2°	+0.70	
3°	+1.03	Vert. Radio Antenna	3°	+0.73	
4°	+0.65		4°	+0.75	
5°	+0.67		5°	+0.69	
6°	+0.64		6°	+0.71	
7°	+0.68		7°	+0.67	
8°	+0.67		8°	+0.73	
9°	+0.58		9°	+0.81	
10°	+0.58		10°	+0.88	
11°	+0.59		11°	+0.88	
12°	+0.69		12°	+1.08	Tall Wide Building
13°	+0.99		13°	+1.08	
14°	+0.98		14°	+1.00	
15°	+0.69		15°	+1.03	
16°	+0.61		16°	+1.18	
17°	+0.63		17°	+1.22	Water Tower
18°	+0.63		18°	+1.22	
19°	+0.75		19°	+1.33	Vert. Radio Tower
20°	+0.71		20°	+1.33	Tall Tree

TABLE 3

TRSB SCS DATA/DEMONSTRATION FLIGHTS AT YOFF AIRPORT, DAKAR

Date	Flight Description	Altitude
2/9/78	ILS CHECK FLIGHTS	Localizer Low
Run 1)	Pre MLS Installation	Approach From
Run 2)	Check Flights of ILS	1500' (458 m)
Run 3)	From 6 NMI (11.1 KM).	
		Localizer Low
Run 4)	Post MLS Installation	Approach From
Run 5)	Check Flights of ILS	1500' (458 m)
Run 6)	From 6 NMI (11.1 KM).	
2/10/78	FIRST DATA FLIGHT	
Run 1	3° Centerline Descent	2000' (610 m)
Run 2	4° Centerline Descent	2000' (610m)
Run 3	3° Centerline Descent	2000' (610 m)
Run 4	10° Left Radial	2000' (610 m)
Run 5	0° Radial, 3° Descent	2000' (610 m)
Run 6	10° Right Radial	2000' (610 m)
Run 7	CCW Orbit, 10 NMI (18.5 Km)	3000' (915 m)
Run 8	CW Orbit, 10 NMI (18.5 Km)	3000' (915 m)
Run 9	Race Track Crosscut @ 10 NMI (18.5 Km) 500' (152 m) Decrements Down to 500 (152 m)	4000' (1220 m)
2/13/78	SECOND DATA FLIGHT	
Run 1	3° Centerline Descent	2000' (610 m)
Run 2	3° Centerline Descent	2000' (610 m)
Run 3	3° Centerline Descent	2000' (610 m)
Run 4	3° Centerline Descent	2000' (610 m)
Run 5	4° Centerline Descent	2000' (610 m)
Run 6	10° Left Radial, 3° Descent	1000' (305 m)
Run 7	10° Left Radial, 4° Descent	1000' (305 m)
Run 8	10° Left Radial, 4° Descent	1000' (305 m)
Run 9	ILS Approach	1000' (305 m)

TABLE 3 (Continued)

Date	Flight Description	Altitude
2/14/78	FIRST DEMONSTRATION FLIGHT (11 observers)	
Run 1	3.5° Centerline	2000' (610 m)
Run 2	4° Centerline Autocoupled	2000' (610 m)
Run 3	3° Centerline	2000' (610 m)
	SECOND DEMONSTRATION FLIGHT (14 observers)	
Run 4	3.5° Centerline	2000' (610 m)
Run 5	4° Centerline Autocoupled	2000' (610 m)
Run 6	3° Centerline	2000' (610 m)
	THIRD DEMONSTRATION FLIGHT (12 observers)	
Run 7	3.5° Centerline	2000' (610 m)
Run 8	4° Centerline Autocoupled	2000' (610 m)
Run 9	3° Centerline	2000' (610 m)
	FOURTH DEMONSTRATION FLIGHT (11 observers)	
Run 10	3.5° Centerline	2000' (610 m)
Run 11	4° Centerline Autocoupled	2000' (610 m)
Run 12	3° Centerline	2000' (610 m)
	FIFTH DEMONSTRATION FLIGHT (7 observers)	
Run 13	3.5° Centerline	2000' (610 m)
Run 14	4° Centerline Autocoupled	2000' (610 m)
Run 15	3° Centerline	2000' (610 m)
2/15/78	FIRST DEMONSTRATION FLIGHT (14 observers)	
Run 1	3.5° Centerline	2000' (610 m)
Run 2	4° Centerline Autocoupled	2000' (610 m)
Run 3	3° Centerline	2000' (610 m)
	SECOND DEMONSTRATION FLIGHT (13 observers)	
Run 4	3.5° Centerline	2000' (610 m)
Run 5	4° Centerline Autocoupled	2000' (610 m)
Run 6	3° Centerline	2000' (610 m)

TABLE 3 (Continued)

Date	Flight Description	Altitude
2/15/78	THIRD DEMONSTRATION FLIGHT (12 observers)	
Run 7	3.5° Centerline	2000' (610 m)
Run 8	4° Centerline Autocoupled	2000' (610 m)
Run 9	3° Centerline	2000' (610 m)

TABLE 4.

AVERAGE DAILY WEATHER OBSERVATIONS METEOROLOGICAL CENTER, YOFF AIRPORT, DAKAR

FEBRUARY 9-15, 1978

Date	Wind Direction	Wind Force	Visibility Range	Temperature Degrees C/F	Humidity Percent
Feb. 9	340°	9 kts	12KM/ 7.5 mi.	21/70	82
Feb. 10	15°	13 kts	12KM/ 7.5 mi.	22/71	78
Feb. 11	8°	12 kts	12KM/ 7.5 mi.	21/70	81
Feb. 12	10°	13 kts	11KM/ 7 mi.	21/70	81
Feb. 13	10°	15 kts	12KM/ 7.5 mi.	21/70	83
Feb. 14	8°	12 kts	12KM/ 7.5 mi.	22/71	85
Feb. 15	5°	10 kts	12KM/ 7.5 mi.	22/71	77

TABLE 5

ICAO (AWOP) FULL AND REDUCED CAPABILITY CONFIGURATION ERROR LIMITS

AWOP System Configuration	Distance to Error Window (Feet)	Permitted Error (2 Sigma) Feet	Degrees
Reduced Capability (Elevation)	4,000	±10	0.14 ±0.10 noise ±0.10 bias
Reduced Capability (Azimuth)	10,000	±40	±0.23 ±0.16 noise ±0.16 bias
Full Capability (Elevation)	1,145	±2.0	±0.10 ±0.07 noise ±0.07 bias
Full Capability (Azimuth)	15,000	±20	±0.076 ±0.054 noise ±0.054 bias

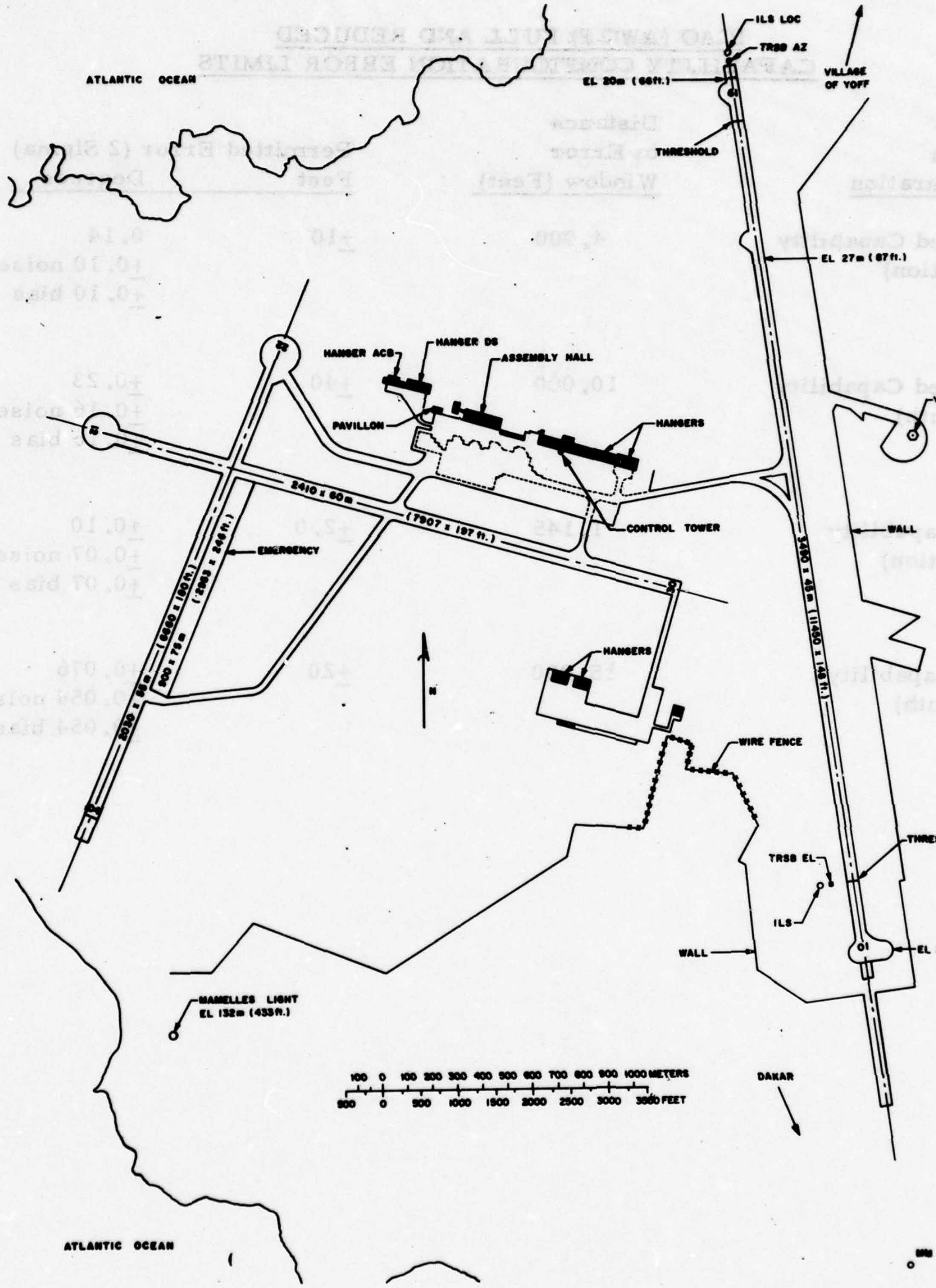


FIGURE 1. GENERAL PLAN OF YOFF AIRPORT, DAKAR

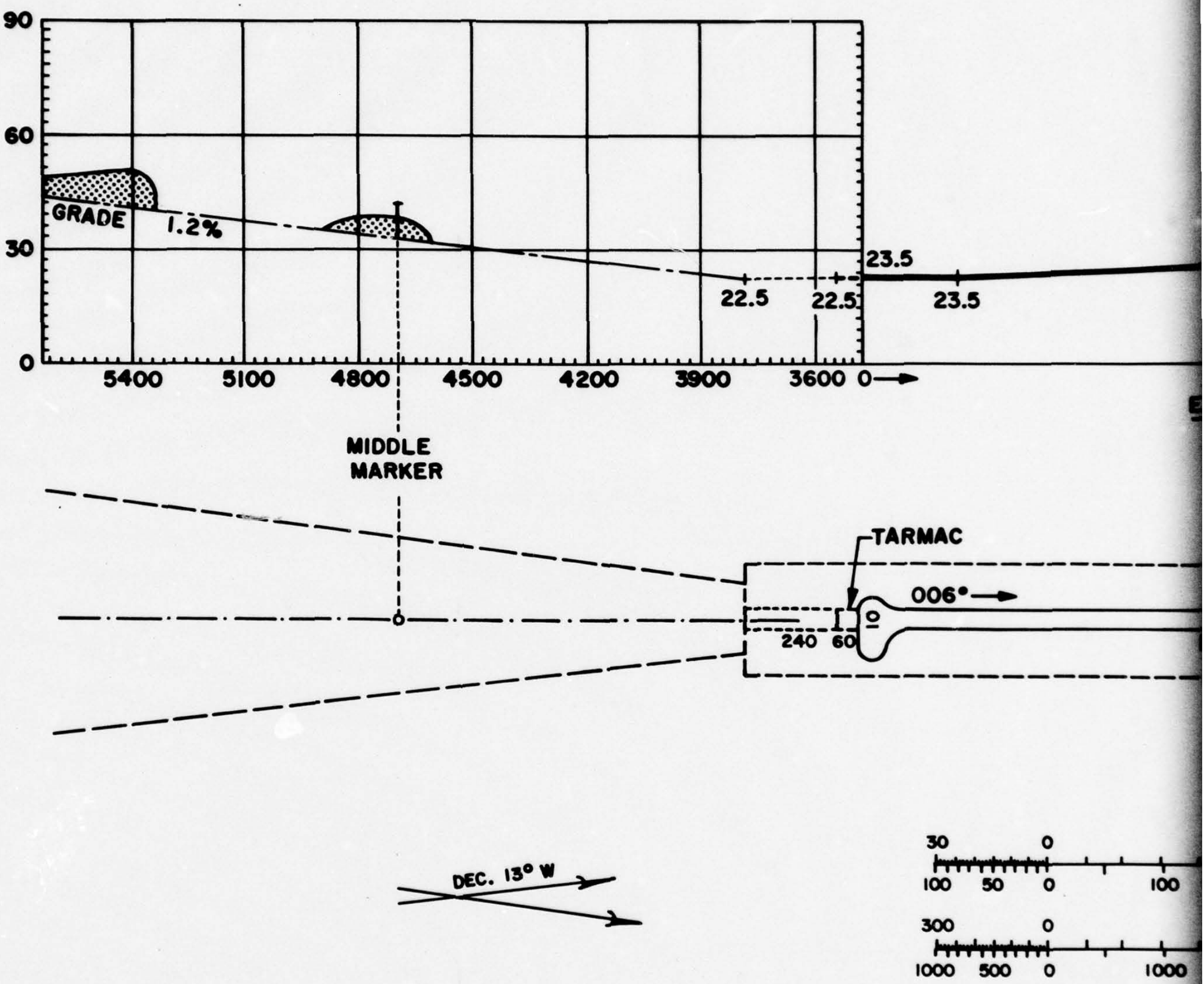
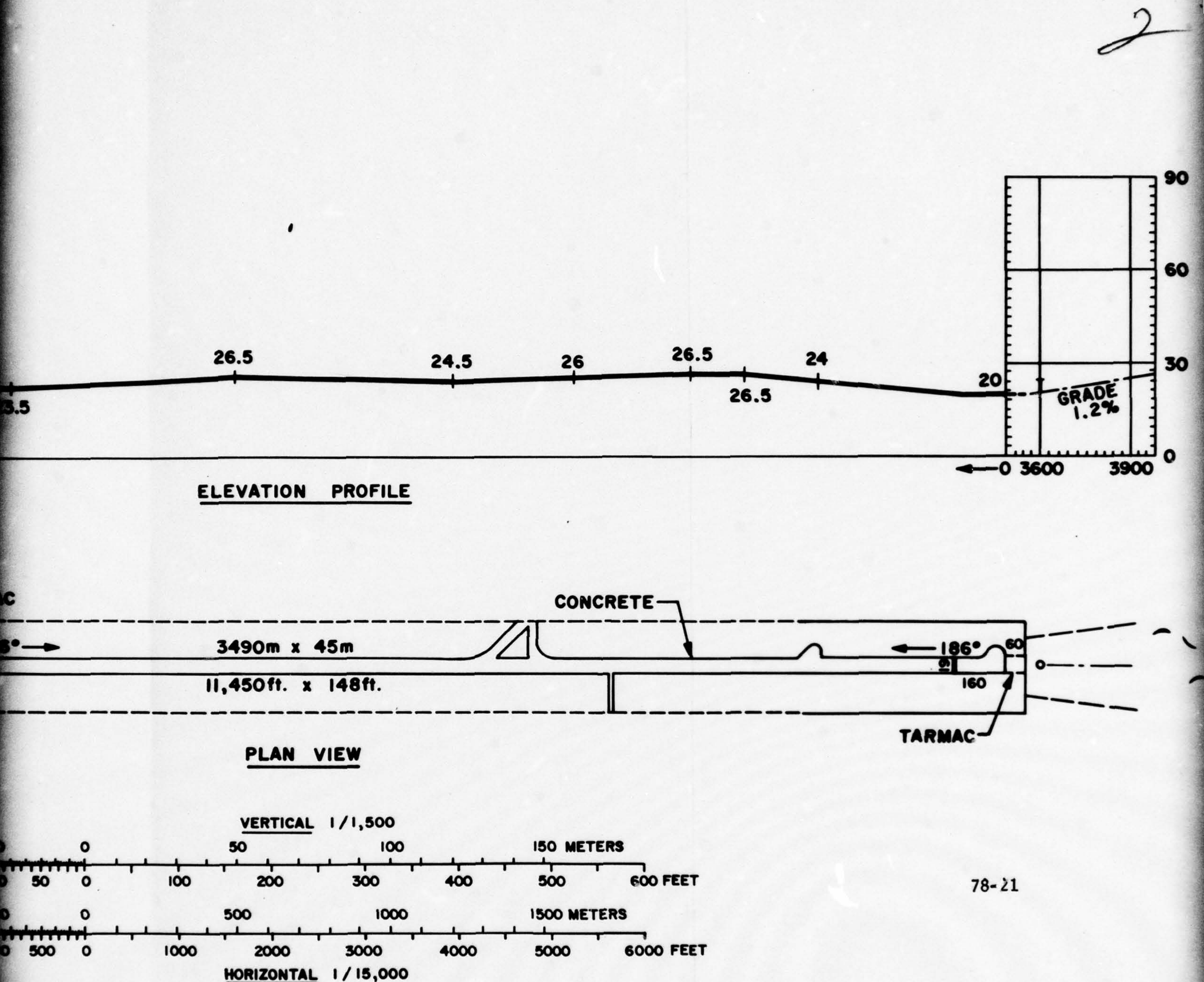


FIGURE 2. PLAN AND ELEVAT



78-21

. PLAN AND ELEVATION VIEWS OF RUNWAY 01, YOFF AIRPORT, DAKAR

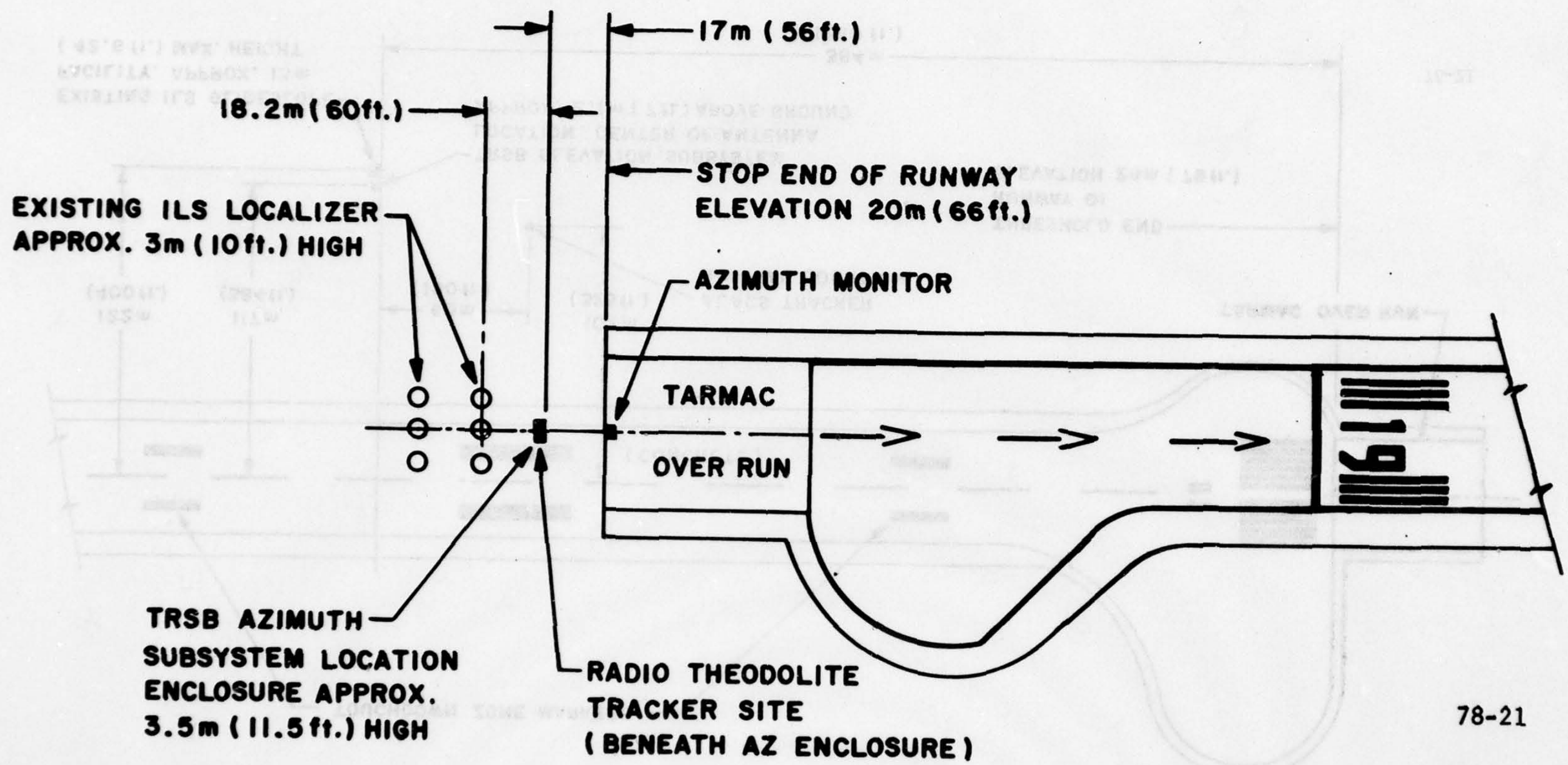


FIGURE 3. TRSB AZIMUTH SUBSYSTEM CONFIGURATION AT STOP END OF RUNWAY 01, YOFF AIRPORT, DAKAR

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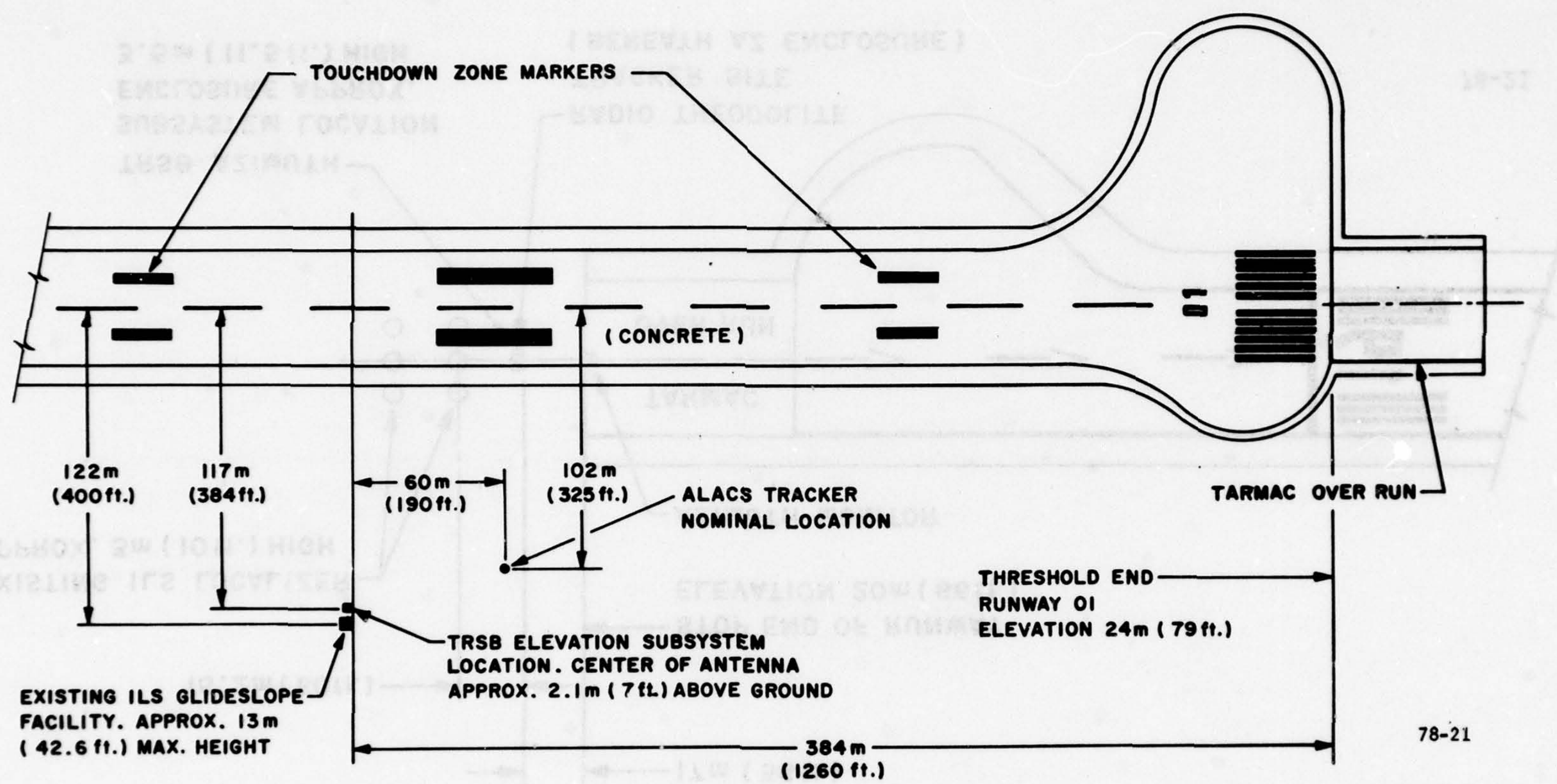


FIGURE 4. TRSB ELEVATION SUBSYSTEM CONFIGURATION NEAR THRESHOLD END OF RUNWAY 01, YOFF AIRPORT, DAKAR

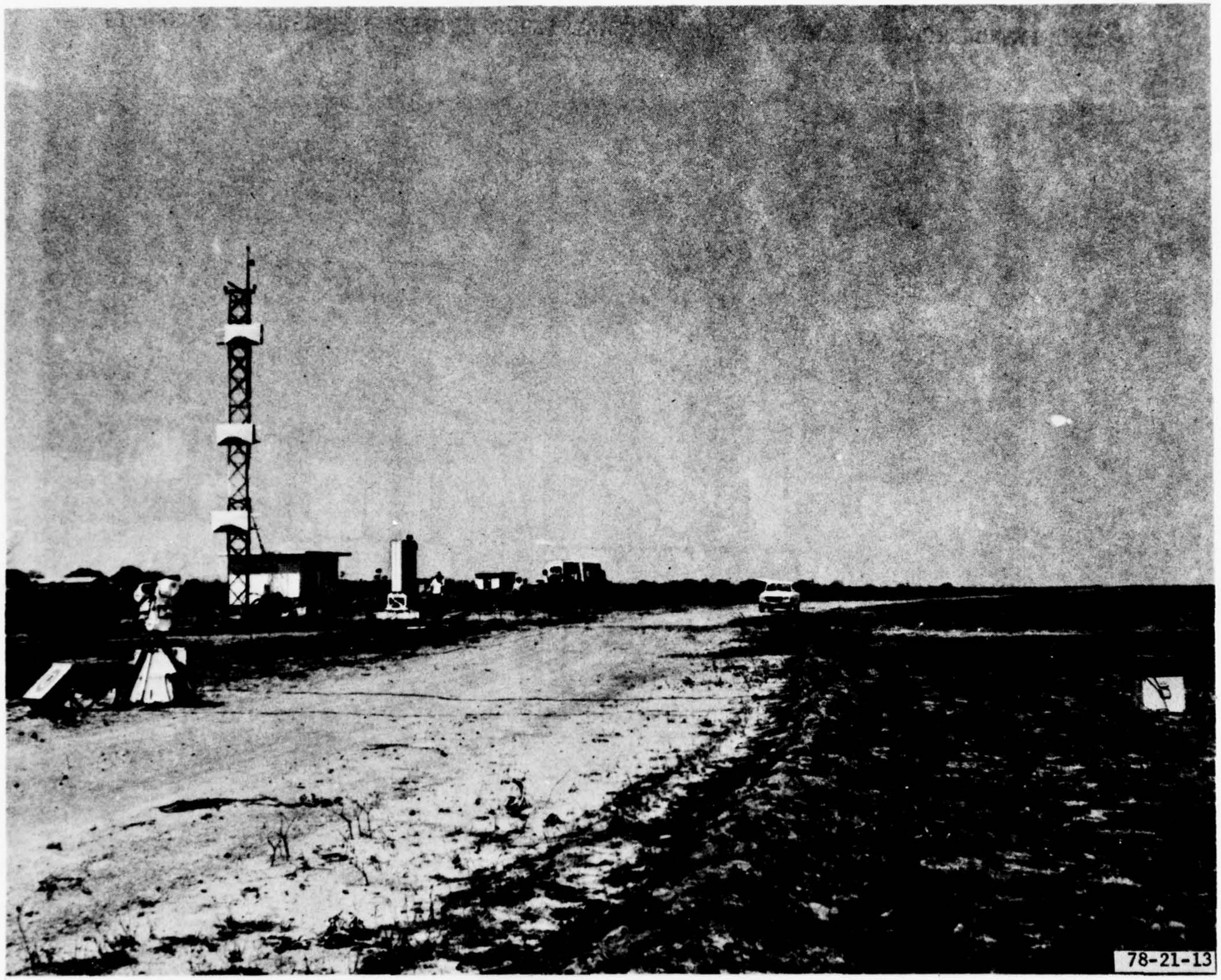


FIGURE 5. TRSB SCS ELEVATION SITE INCLUDING EXISTING ILS FACILITY, TRSB SITE POWER PLANT, AND THE ALACS TRACKER IN THE FOREGROUND

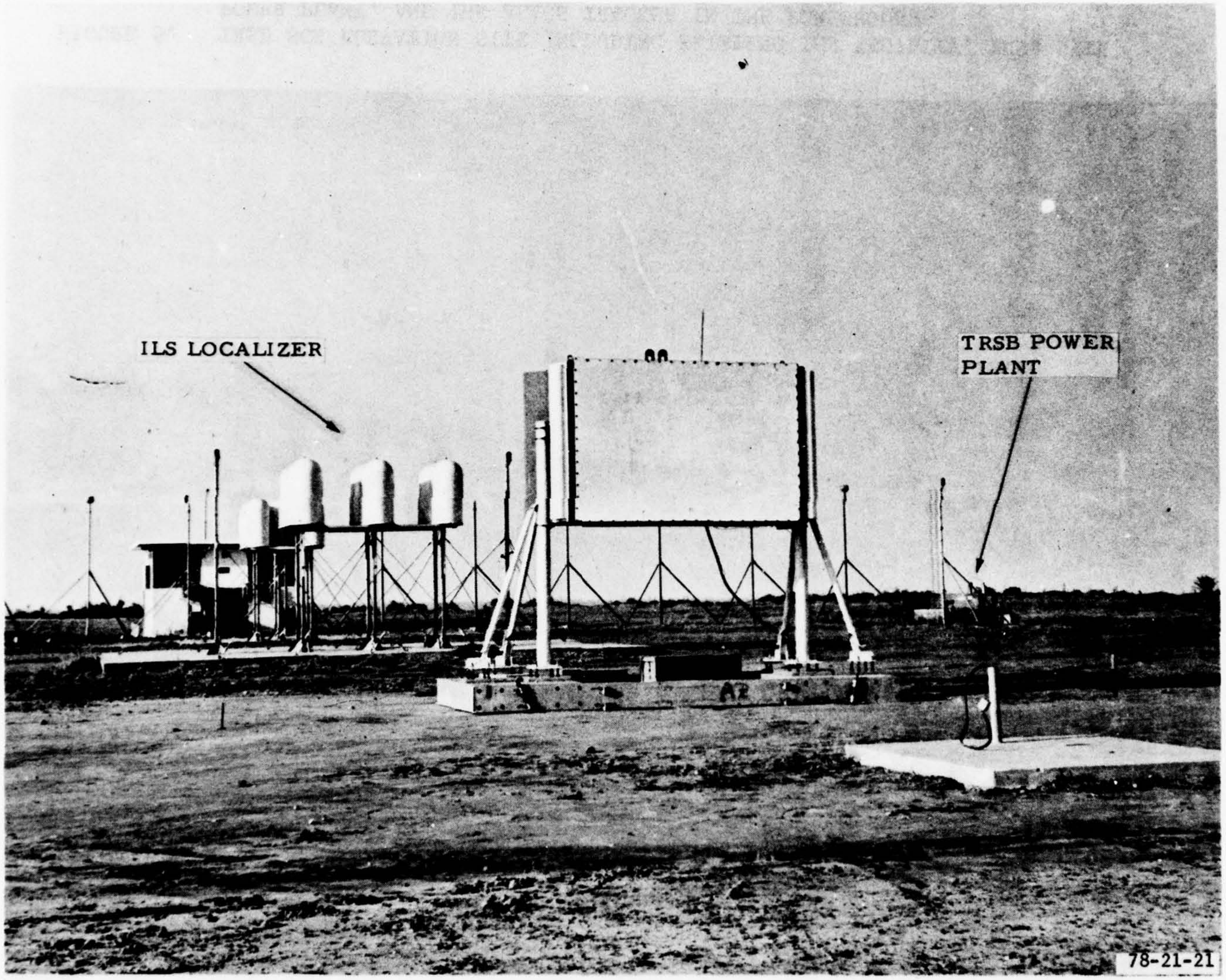


FIGURE 6. TRSB SCS AZIMUTH SUBSYSTEM INSTALLED AT STOP END OF RUNWAY 01, YOFF AIRPORT, DAKAR

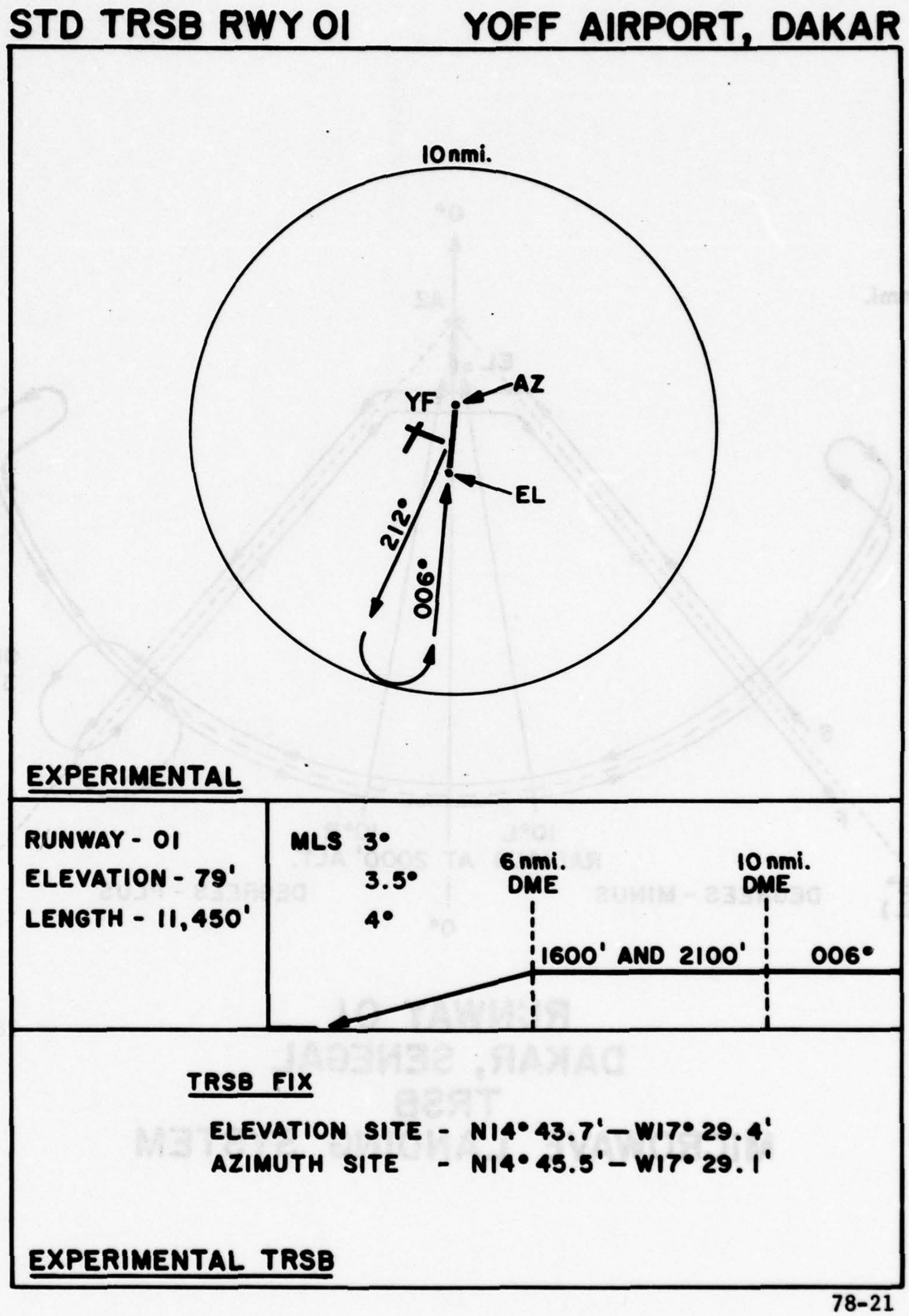


FIGURE 7. **STRAIGHT-IN APPROACH/LANDING PATHWAY USED IN TRSB SCS DEMONSTRATIONS AT YOFF AIRPORT, DAKAR**

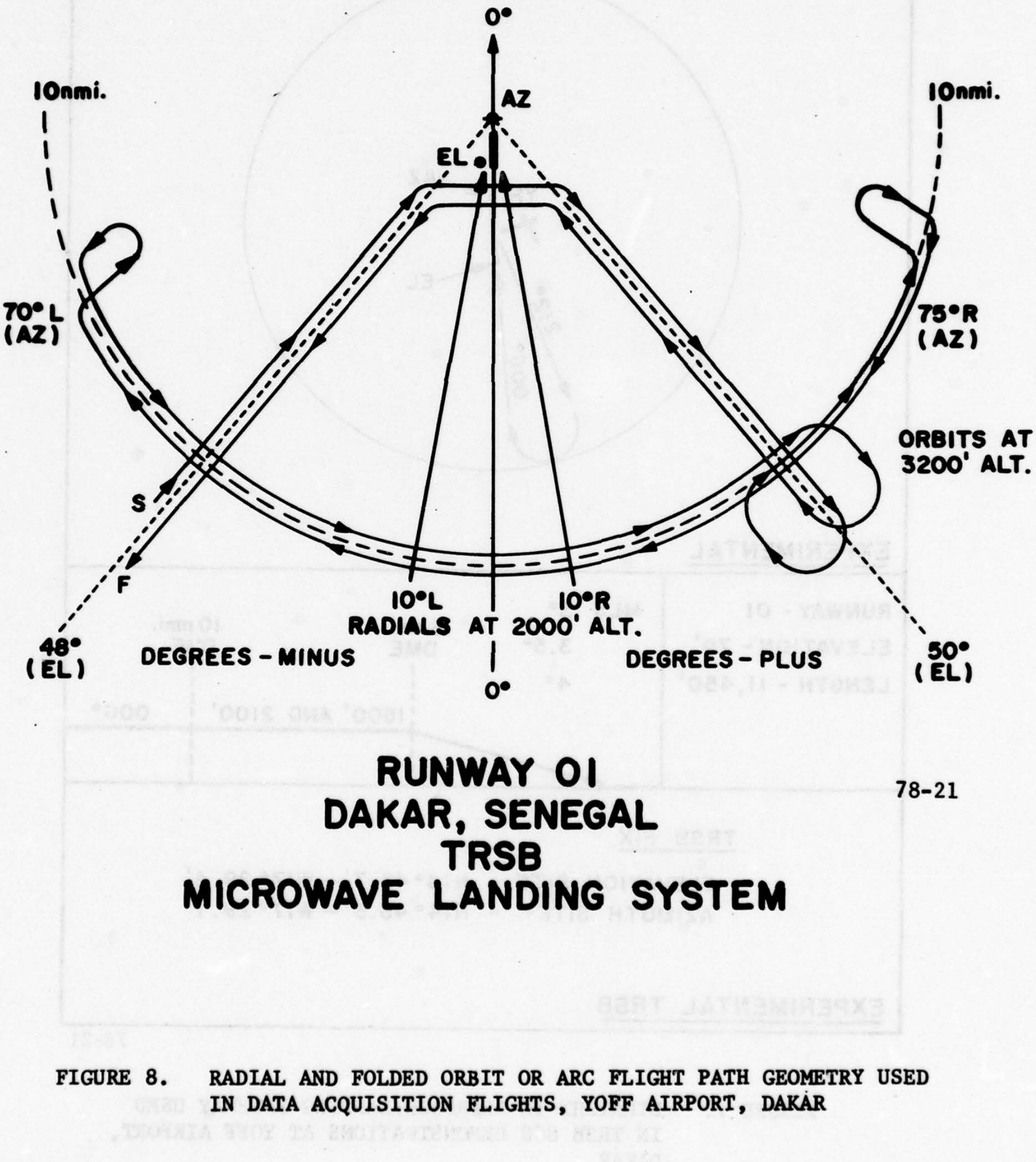


FIGURE 8. RADIAL AND FOLDED ORBIT OR ARC FLIGHT PATH GEOMETRY USED IN DATA ACQUISITION FLIGHTS, YOFF AIRPORT, DAKAR

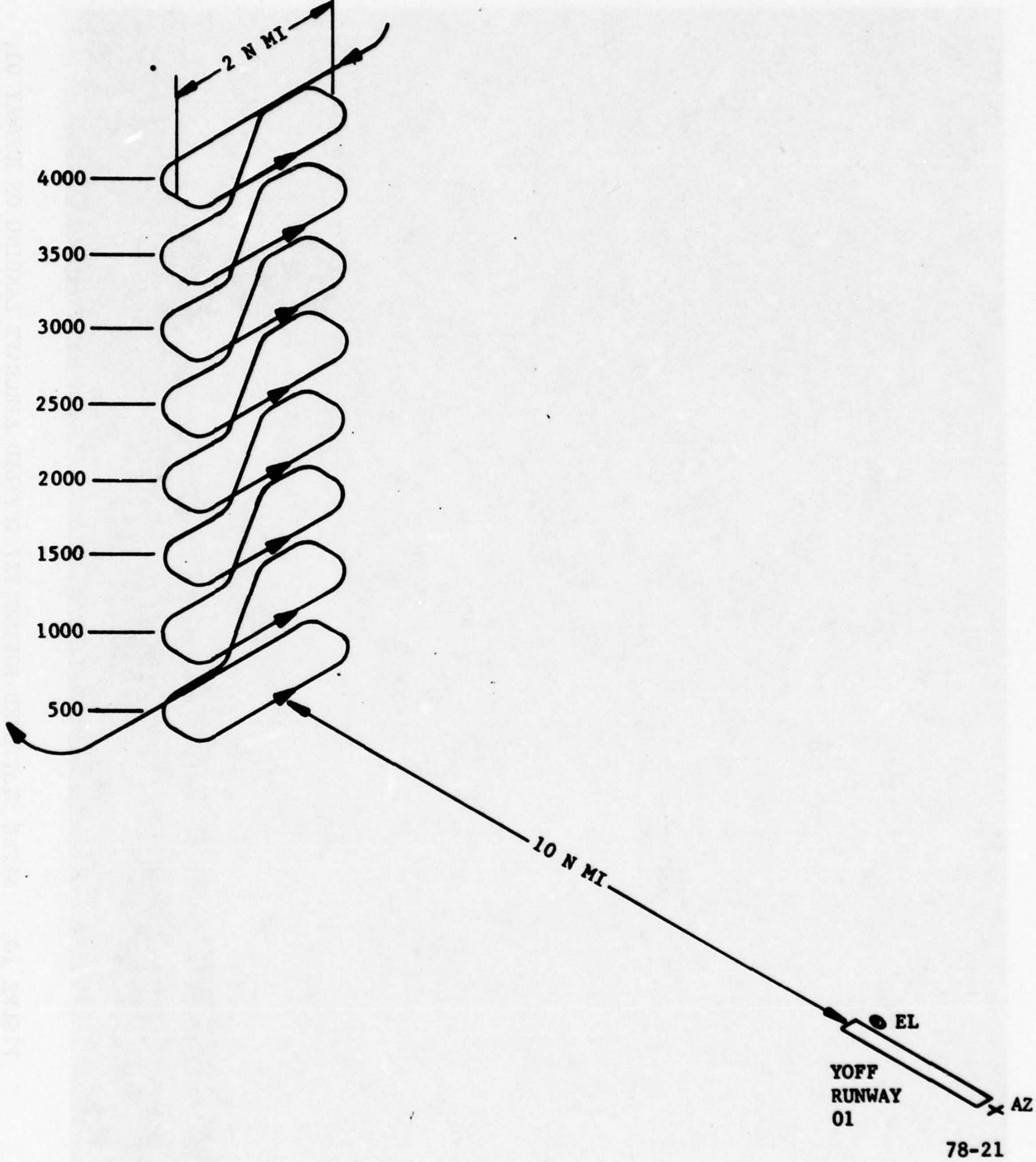


FIGURE 9. DESCENDING RACETRACK SPIRAL FROM 4000 FT. (1.2 km) FLIGHT LEVEL 10 nmi (18.5 km) FROM RUNWAY 01, YOFF AIRPORT, DAKAR

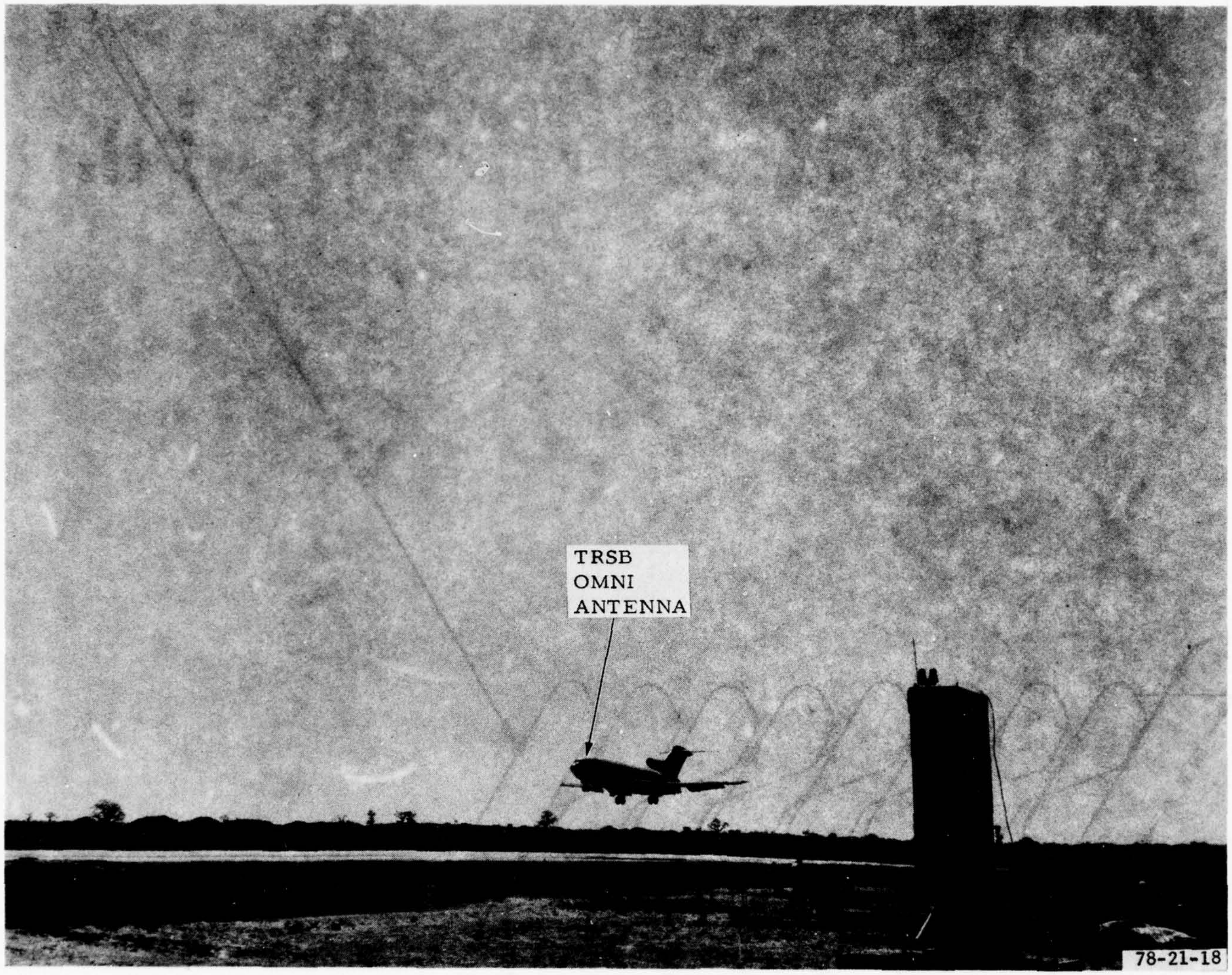


FIGURE 10. NAFEC STATIONED BOEING 727 TESTBED AIRCRAFT LANDING ON RUNWAY 01, YOFF AIRPORT, UNDER TRSB GUIDANCE

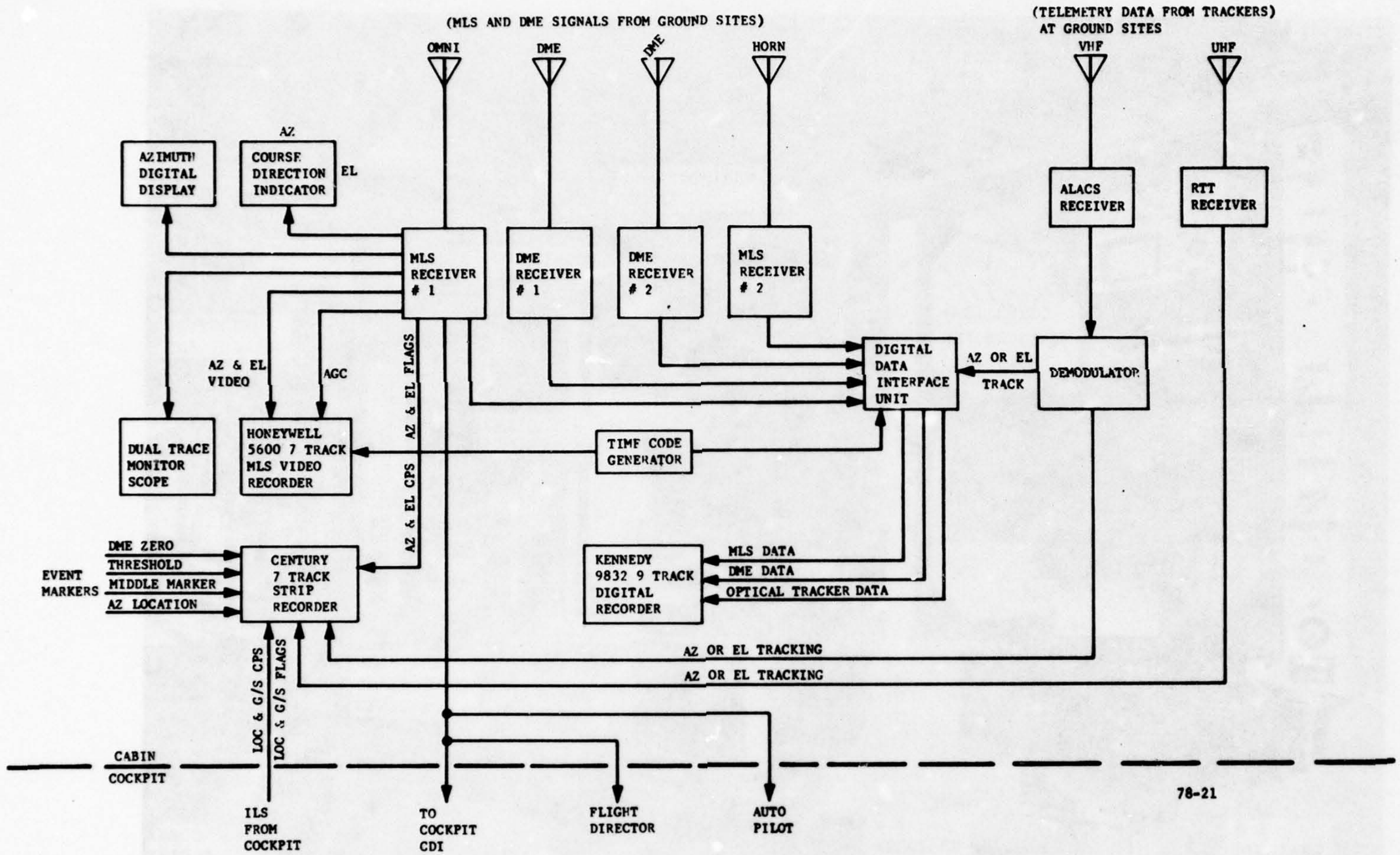


FIGURE 11. TRSB AIRBORNE TESTBED INSTRUMENTATION DIAGRAM, FAA N-40, B727 AIRCRAFT

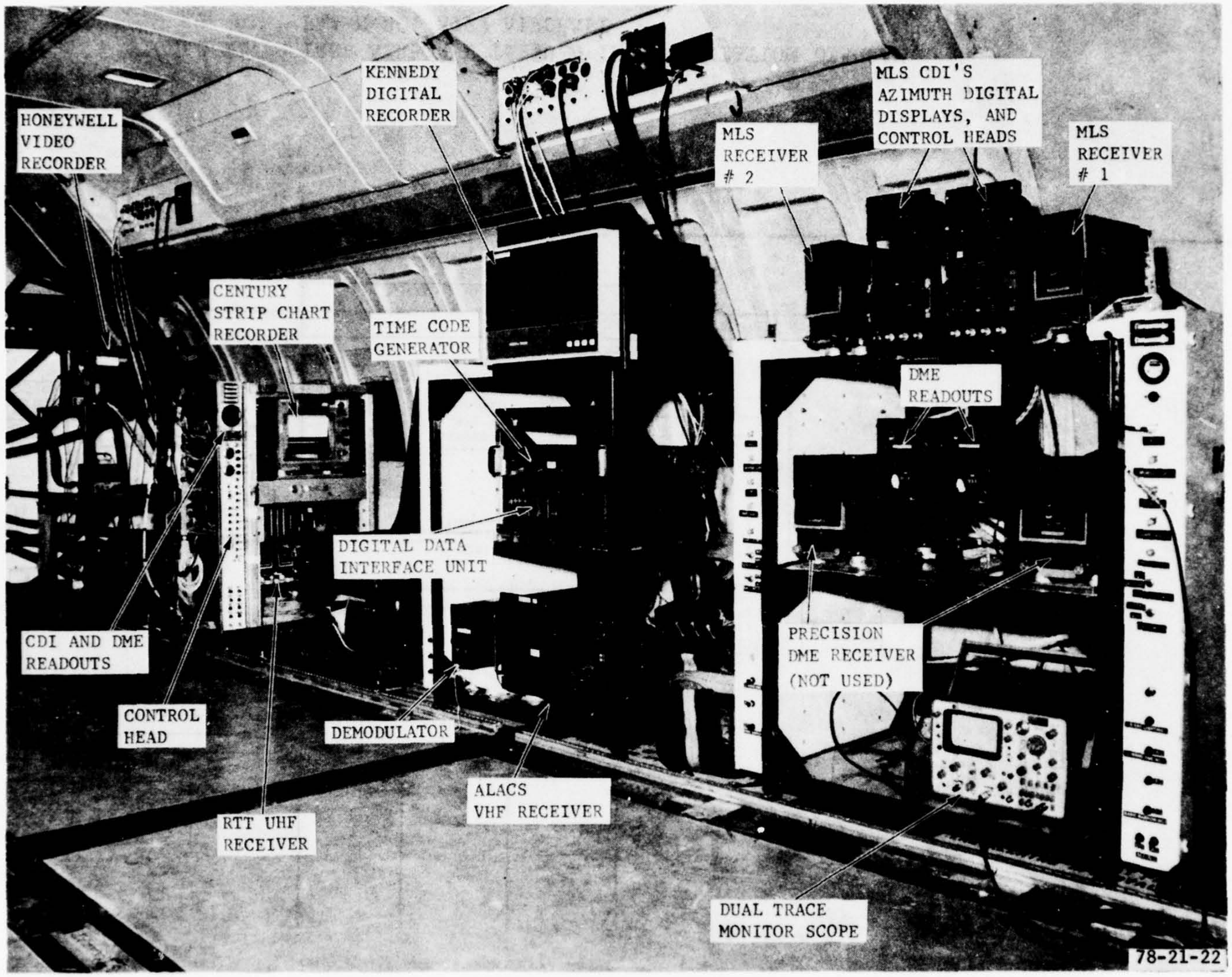


FIGURE 12. TRSB AIRBORNE TESTBED EQUIPMENT CONFIGURATION, FAA N-40, B-727 AIRCRAFT

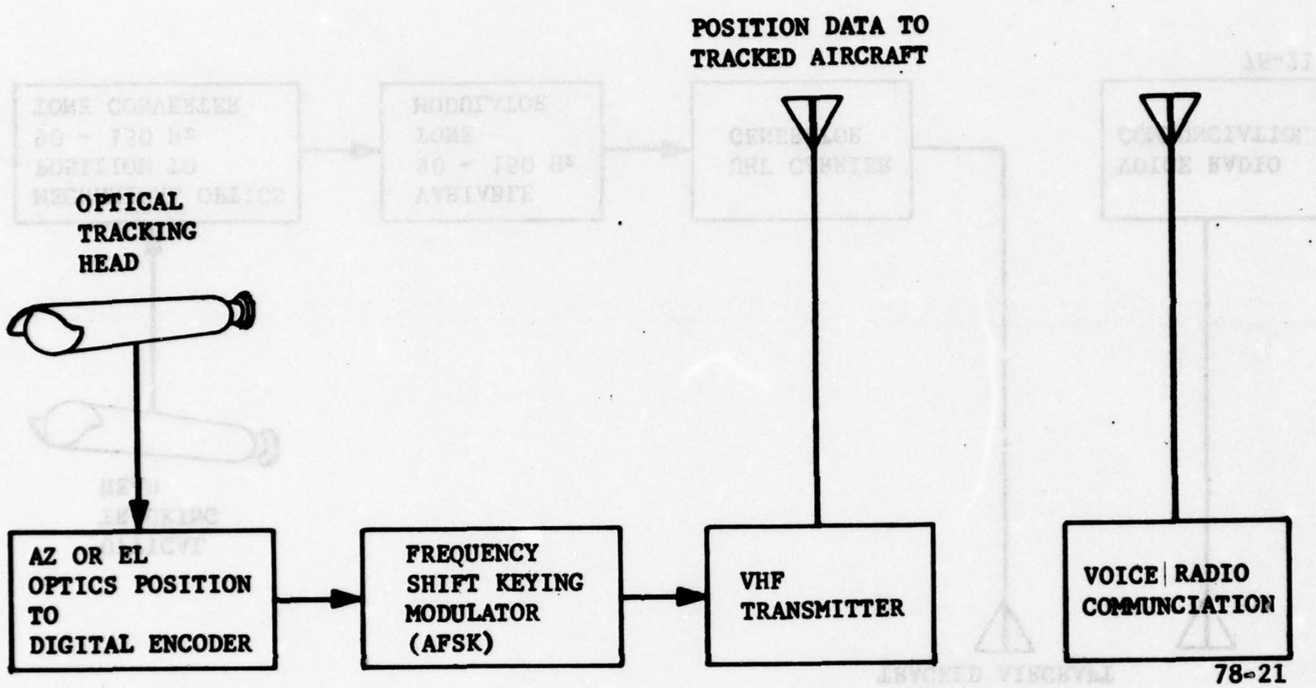


FIGURE 13. AIRBORNE LANDING AND CALIBRATION SYSTEM (ALACS) TRACKER ELEMENTS AS USED AT YOFF AIRPORT TRSB DEMONSTRATIONS, DAKAR

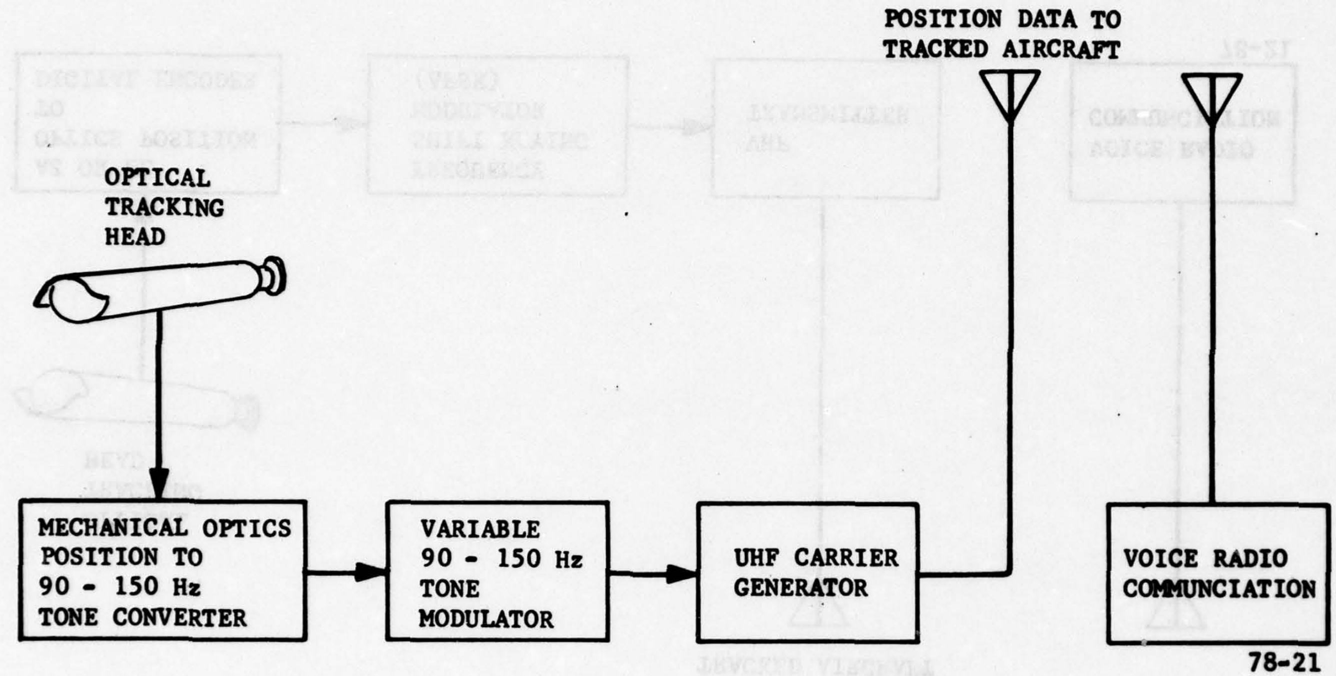


FIGURE 14. RADIO TELEMETRIC THEODOLITE (RTT) TRACKER ELEMENTS AS USED AT YOFF AIRPORT TRSB DEMONSTRATIONS, DAKAR

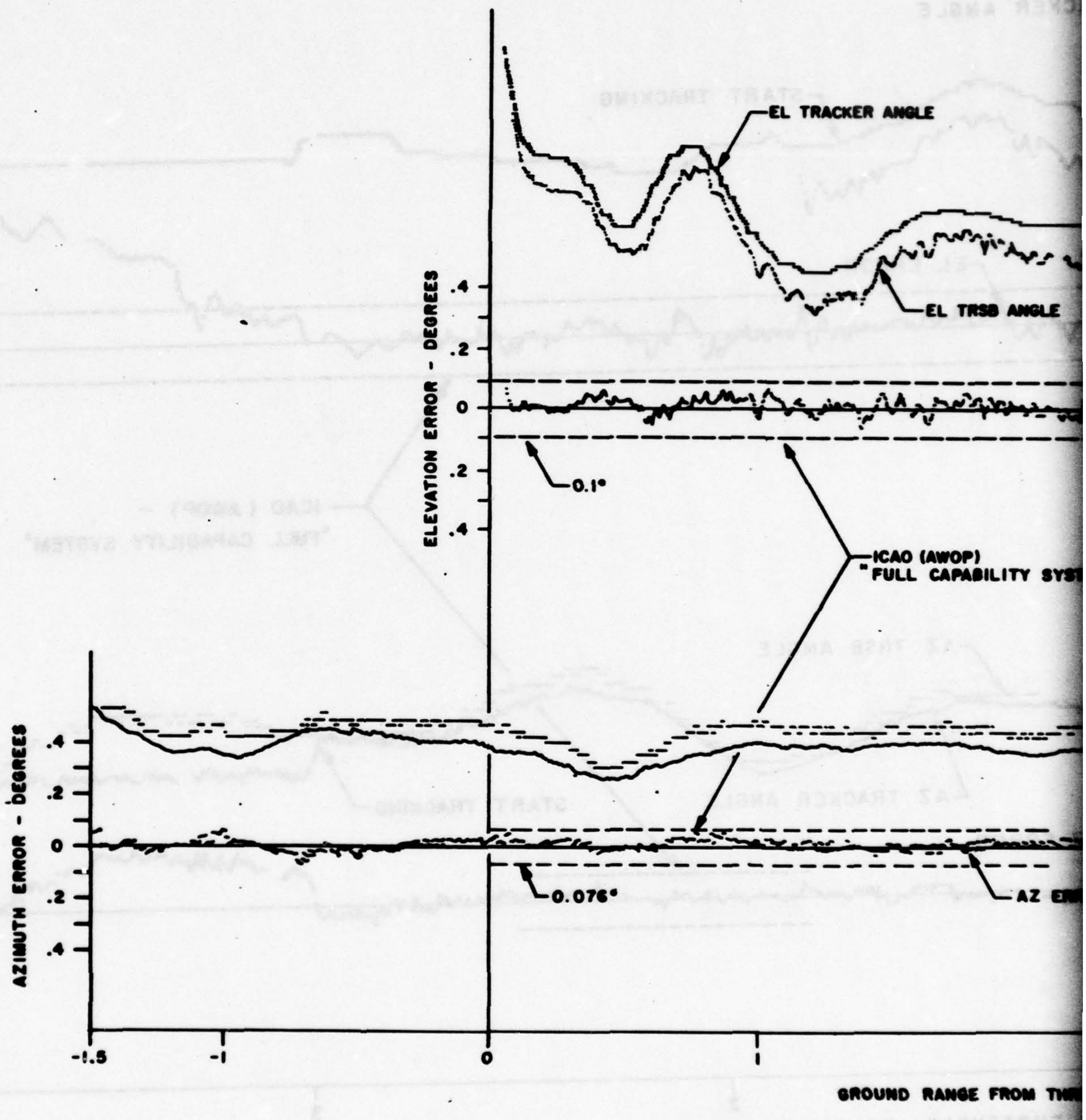
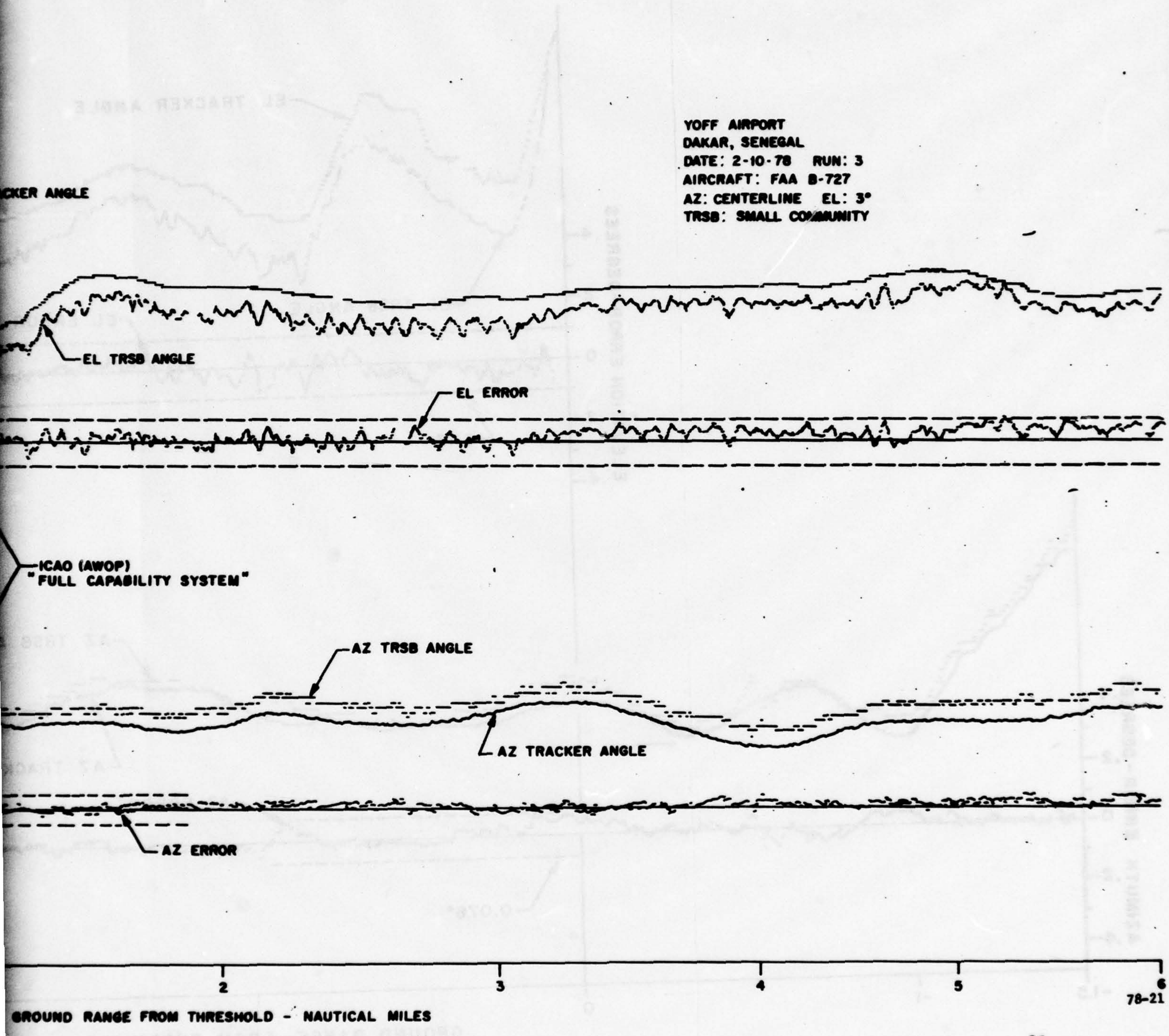


FIGURE 15. ANALOG DATA PLO



ANALOG DATA PLOT OF 2/10/78, B-727, RUN 3

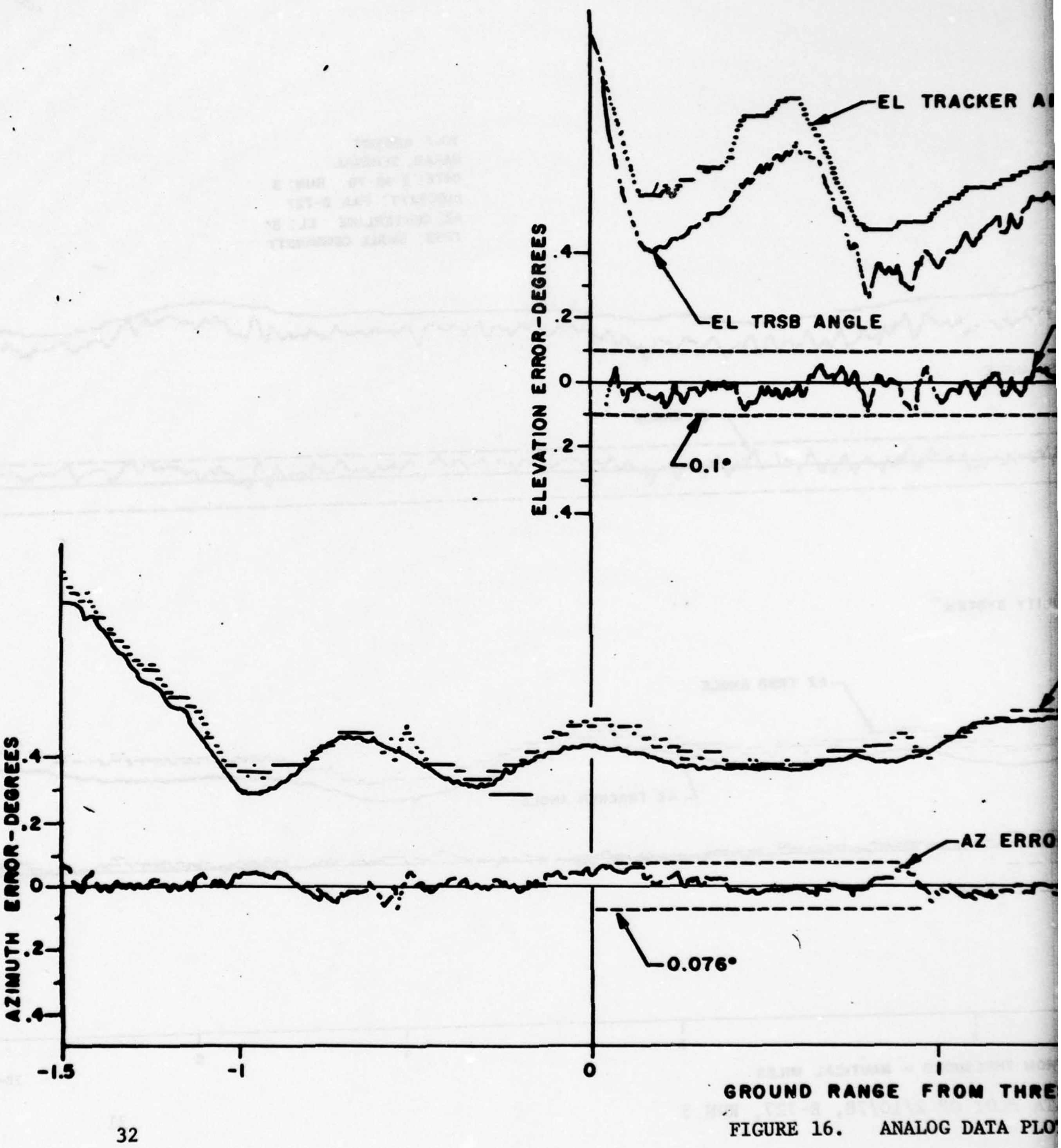
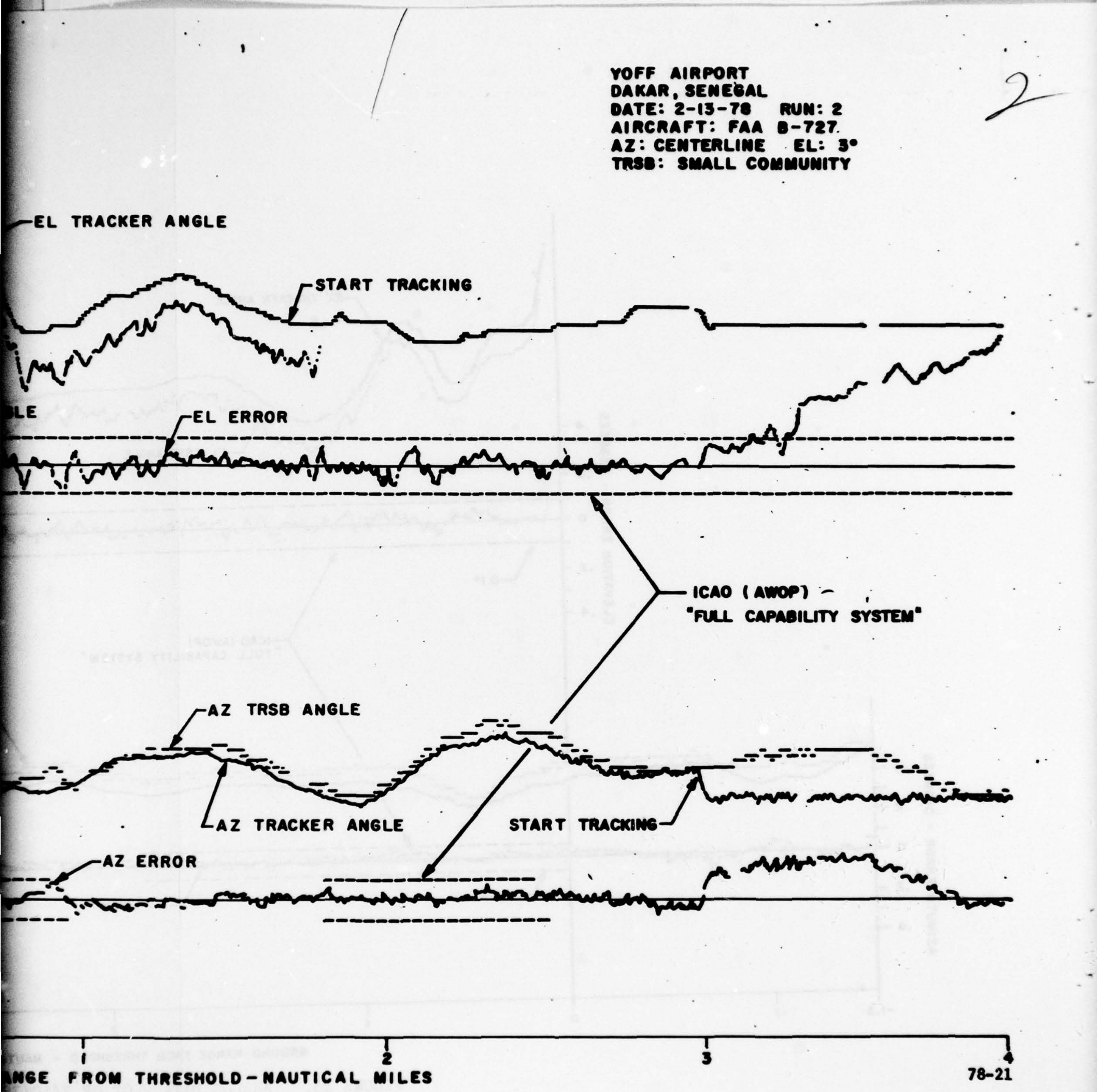


FIGURE 16. ANALOG DATA PLO



ANALOG DATA PLOT OF 2/13/78, B-727, RUN 2

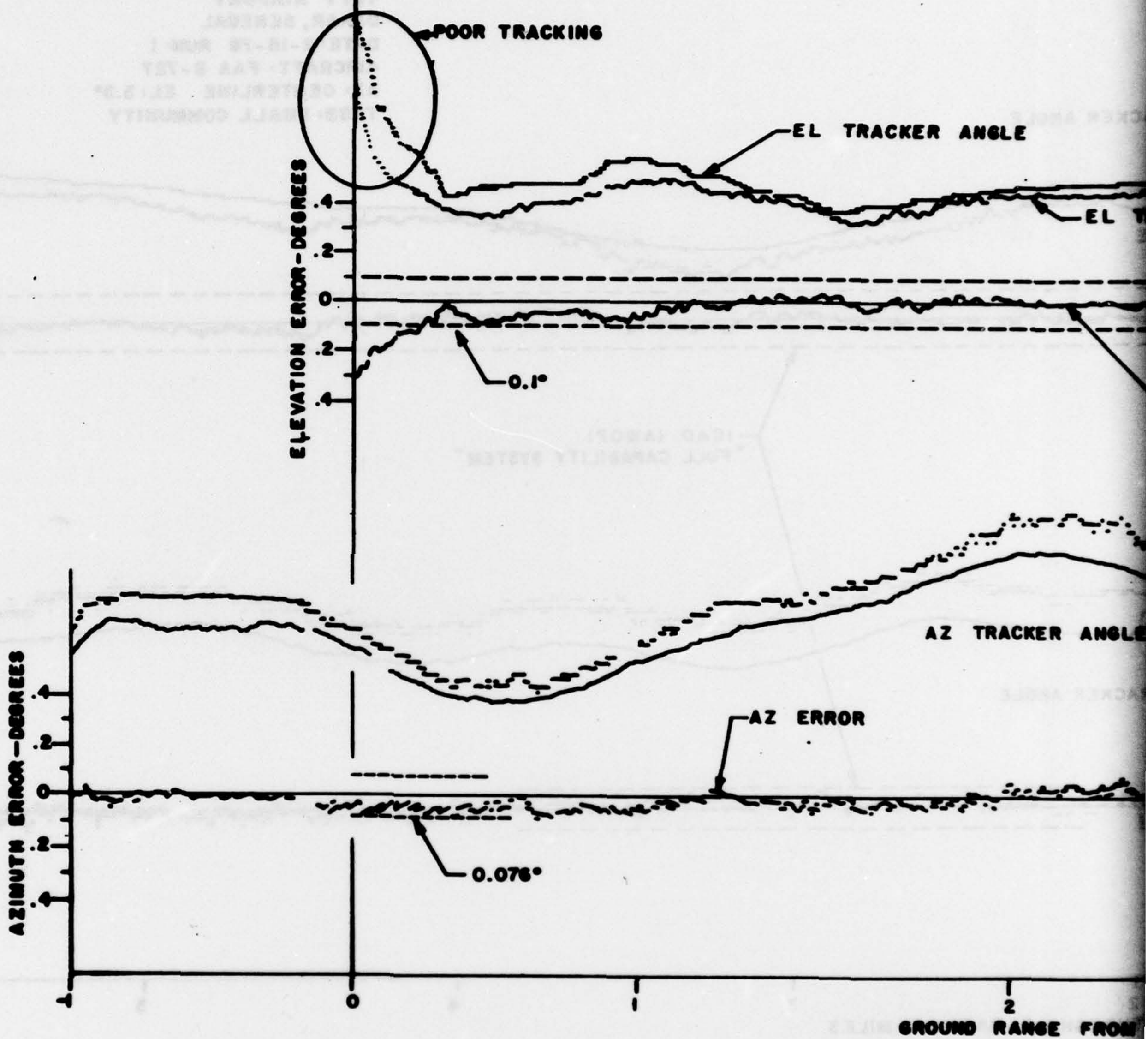
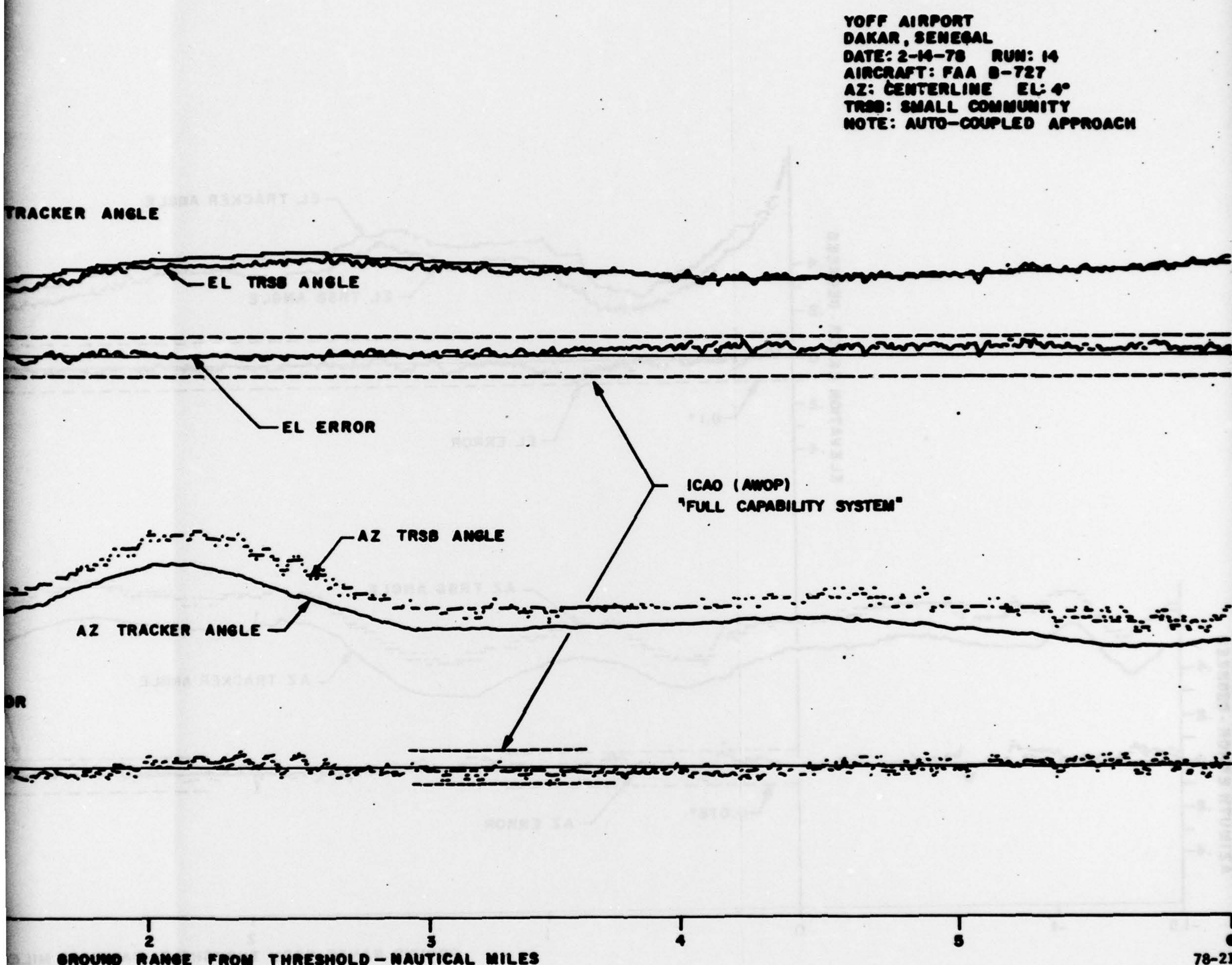


FIGURE 17. ANALOG DATA



GURE 17. ANALOG DATA PLOT OF 2/14/78, B-727, RUN 14

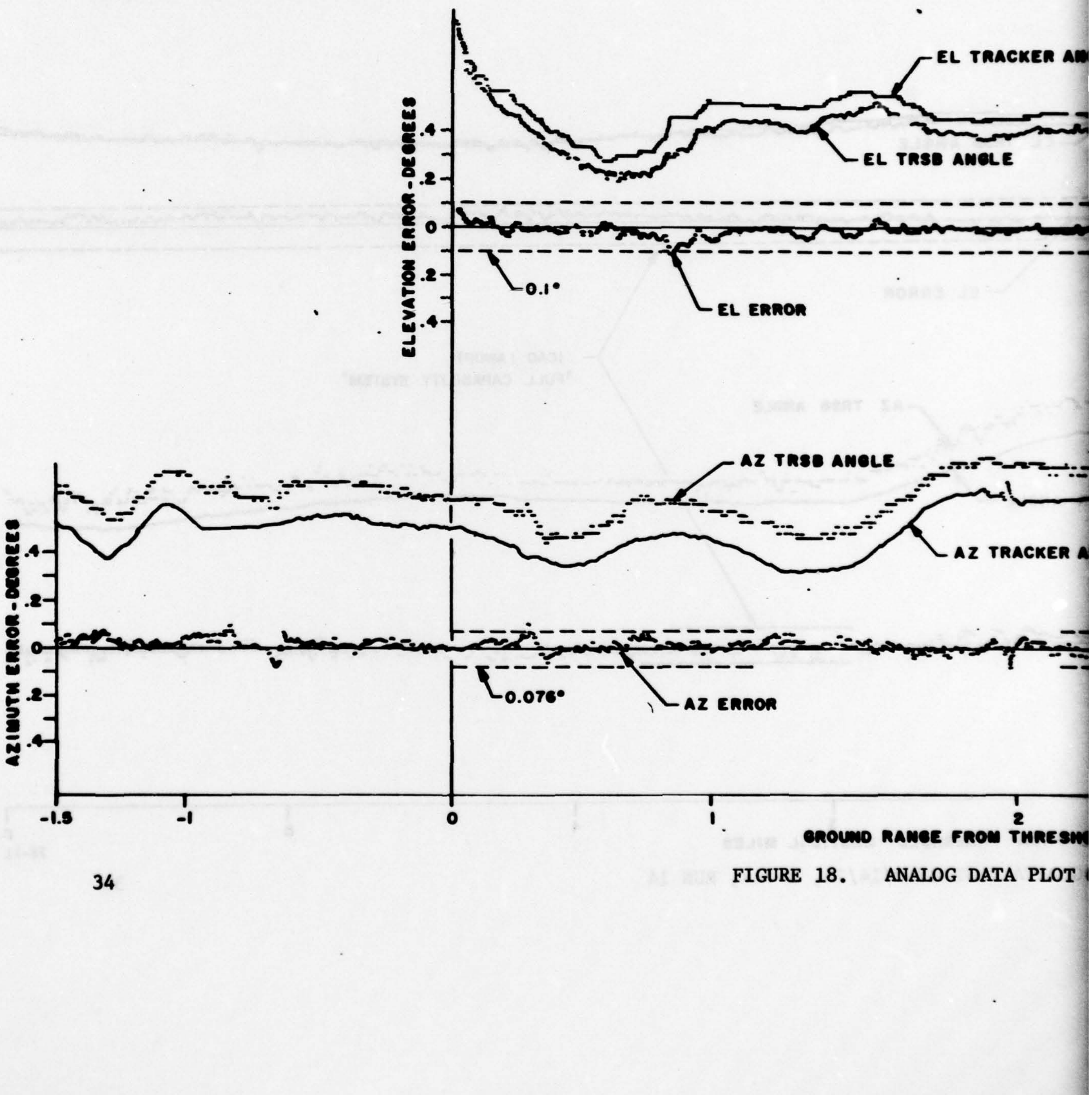
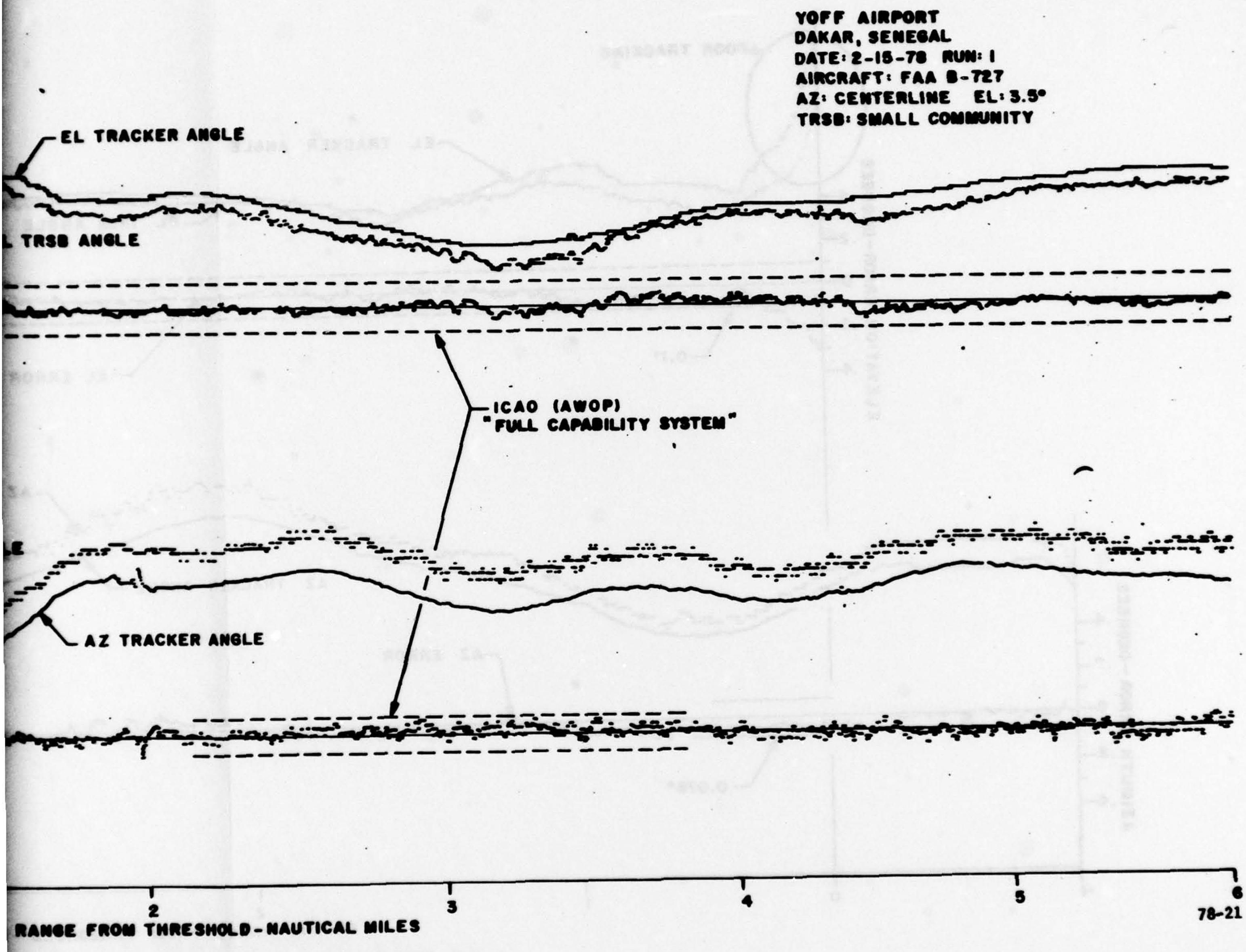


FIGURE 18. ANALOG DATA PLOT



ANALOG DATA PLOT OF 2/15/78, B-727, RUN 1

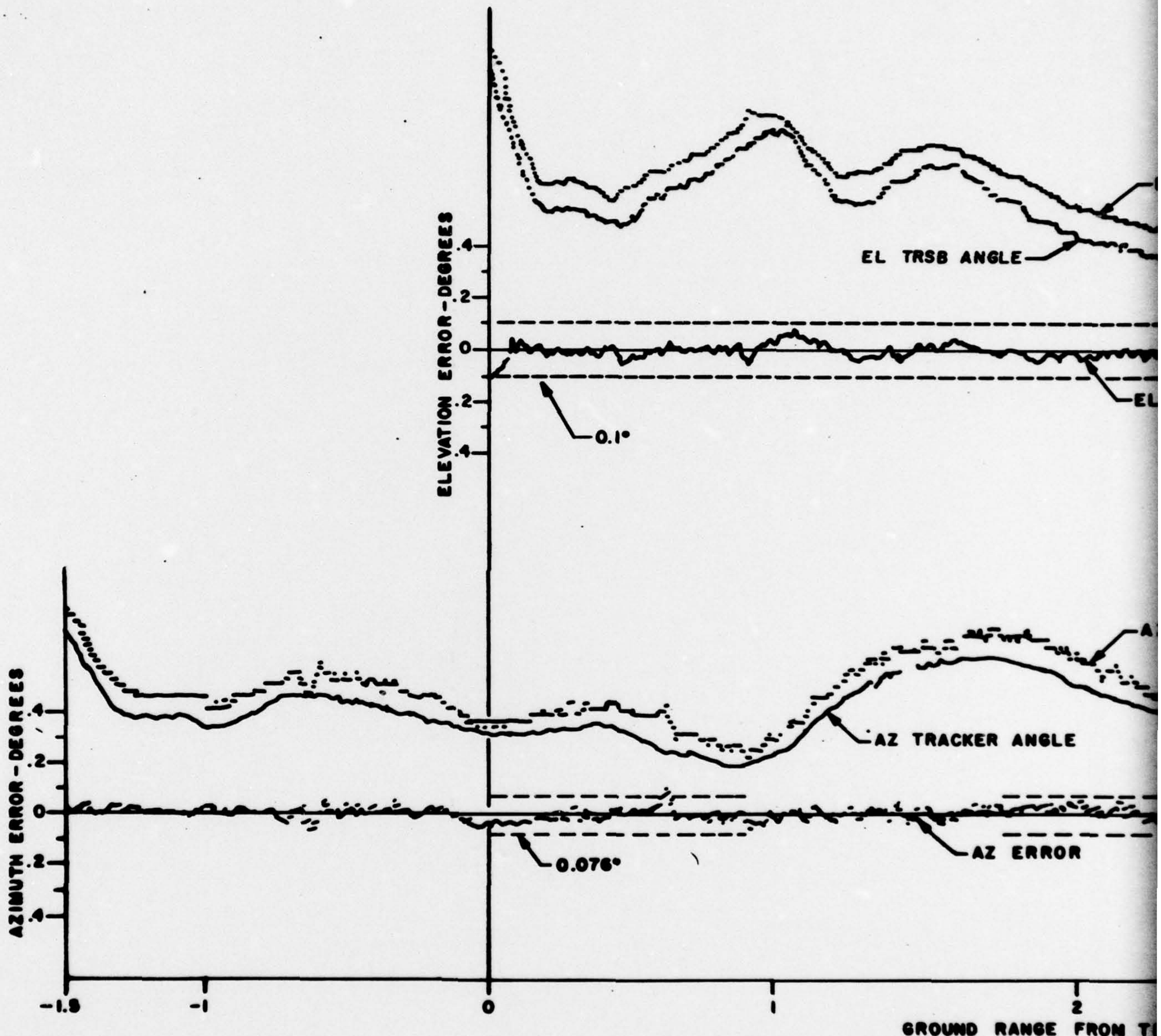
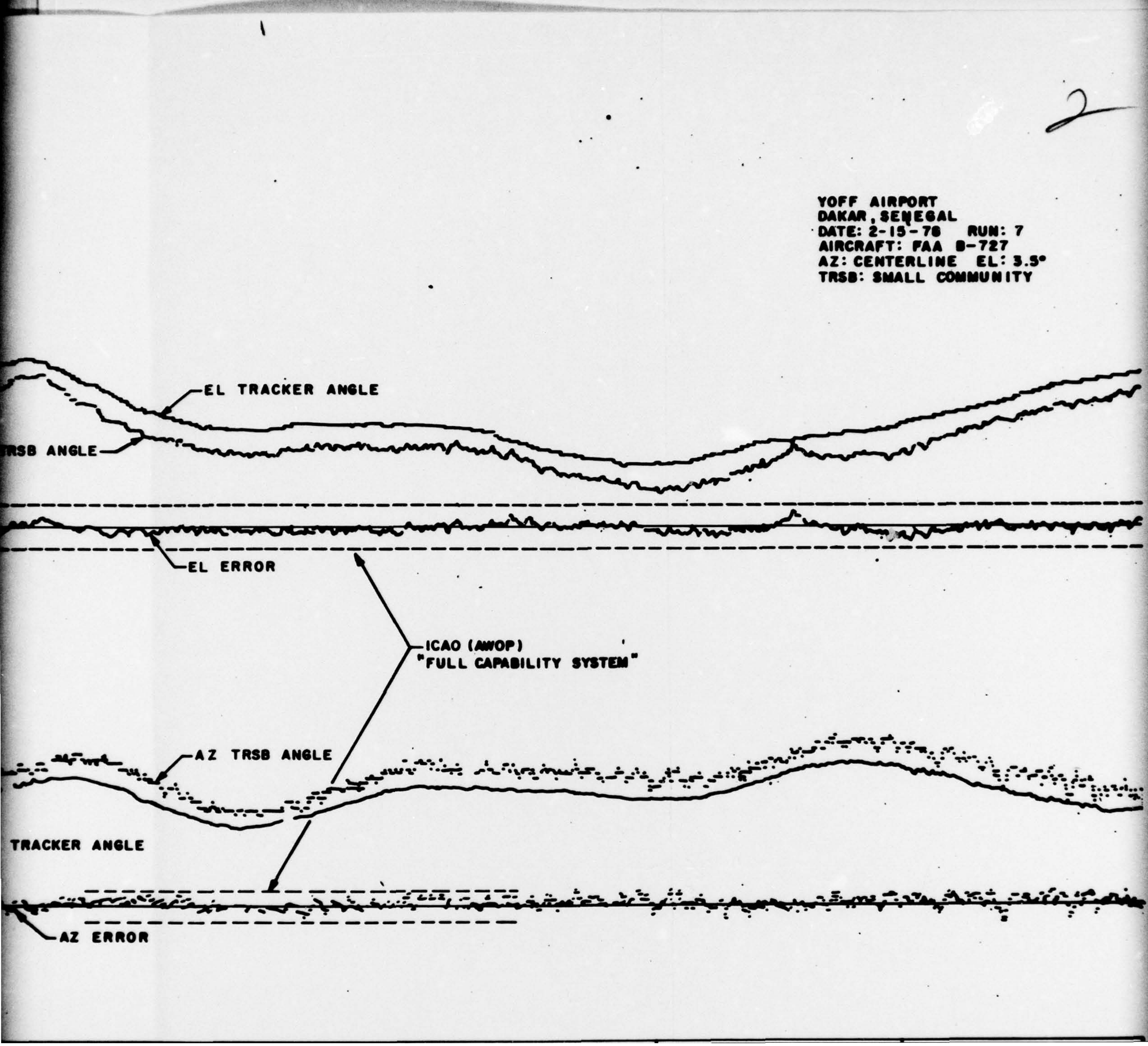


FIGURE 19. ANALOG DATA P


2
YOFF AIRPORT
DAKAR, SENEGAL
DATE: 2-15-78 RUN: 7
AIRCRAFT: FAA B-727
AZ: CENTERLINE EL: 3.5°
TRSB: SMALL COMMUNITY
EL TRACKER ANGLE
TRSB ANGLE
EL ERROR
ICAO (AWOP)
"FULL CAPABILITY SYSTEM"
AZ TRSB ANGLE
TRACKER ANGLE
AZ ERROR

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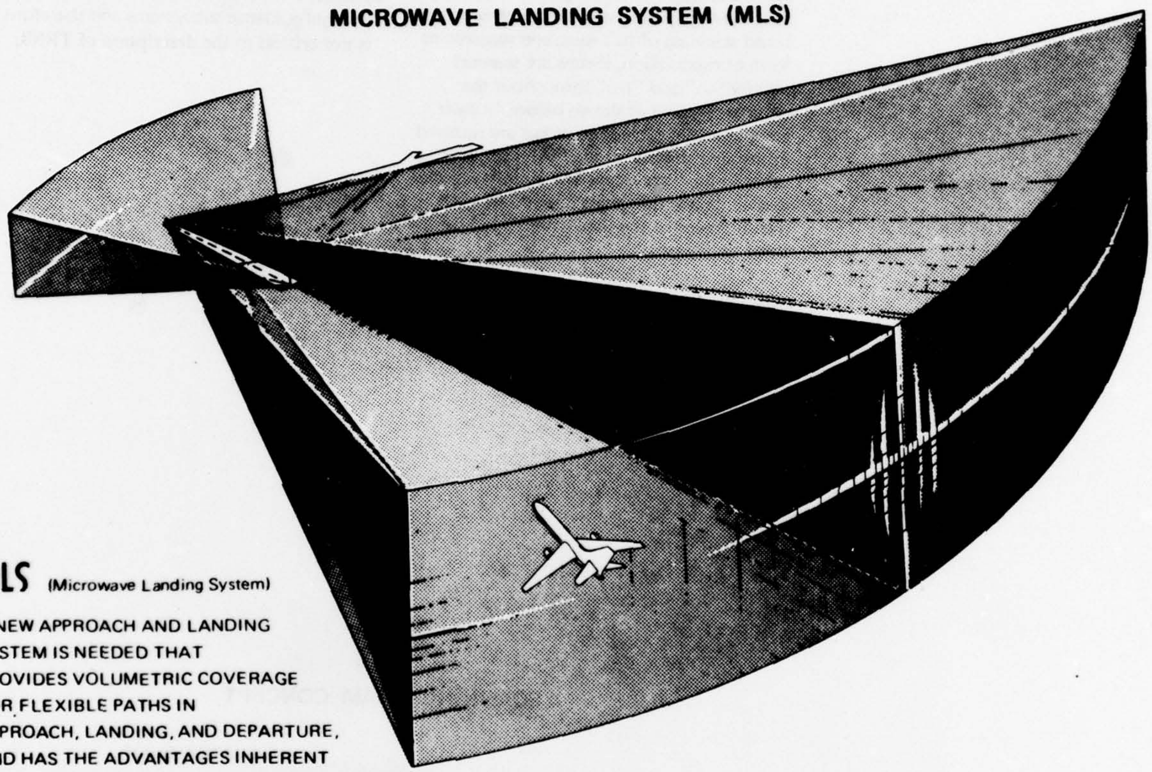
APPENDIX

MICROWAVE LANDING SYSTEM (MLS)



MLS (Microwave Landing System)

A NEW APPROACH AND LANDING SYSTEM IS NEEDED THAT PROVIDES VOLUMETRIC COVERAGE FOR FLEXIBLE PATHS IN APPROACH, LANDING, AND DEPARTURE, AND HAS THE ADVANTAGES INHERENT WITH OPERATING AT MICROWAVE FREQUENCIES

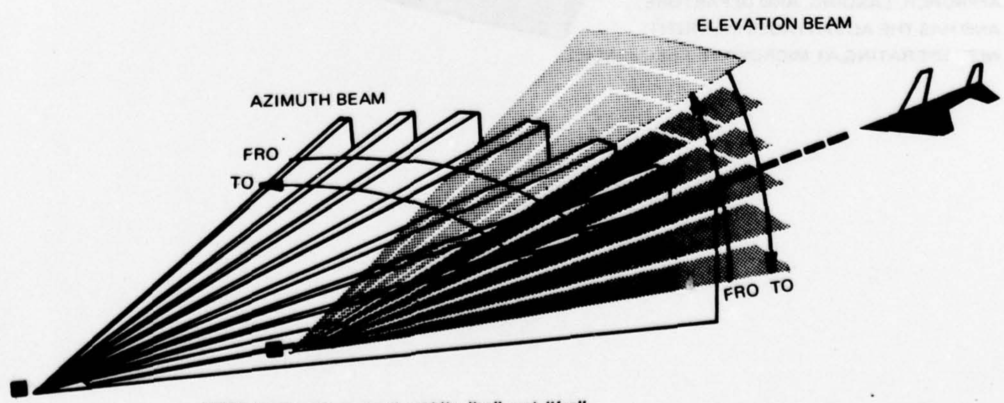
TIME REFERENCE SCANNING BEAM (TRSB) MLS IS AN AIR-DERIVED APPROACH AND LANDING SYSTEM. An aircraft can determine its position in space by making two angle measurements and a range measurement, A simple ground-to-air data capability provides airport and runway identification and other operational data (such as wind speed and direction, site data, and system status).

FAN BEAMS PROVIDE ALL ANGLE GUIDANCE (APPROACH AZIMUTH, ELEVATION, FLARE, AND MISSED APPROACH). The TRSB ground transmitter supplies angle information through precisely timed scanning of its beams and requires no form of modulation. Beams are scanned rapidly "to" and "fro" throughout the coverage volume as shown below. In each complete scan cycle, two pulses are received in the aircraft—one in the "to" scan, the other in the "fro" scan. The aircraft receiver derives its position angle directly from the measurement of the time difference between these two pulses.

RANGE IS COMPUTED IN THE CONVENTIONAL MANNER. TRSB proposes to use L-Band Distance Measuring Equipment (DME) that is compatible with existing navigation equipment. It provides improved accuracy and channelization capabilities. The required 200 channels can be made available by assignment or sharing of existing channels, using additional pulse multiplexing. The ground transponder is typically collocated with the approach azimuth subsystem.

NOTE: The DME (ranging) function is not discussed in detail because it is independent of angle guidance subsystems and therefore **is not critical to the description of TRSB.**

SCANNING BEAM CONCEPT



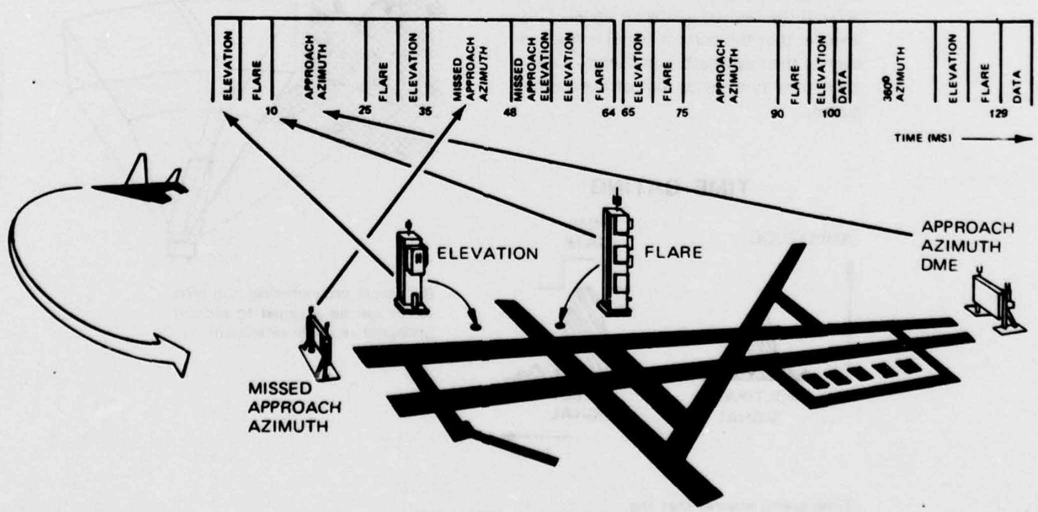
TRSB beams are scanned rapidly "to" and "fro" (back and forth for azimuth, down and up for elevation) at a precise rate

TRSB USES A TIME-SEQUENCED SIGNAL FORMAT FOR ANGLE AND DATA FUNCTIONS. Angle and data functions (that is, approach azimuth, elevation, flare, missed-approach guidance, and auxiliary data) are sequentially transmitted by the ground station on the same channel. Primary operation is C-band, with 300 KHz spacing between channels. However the format is compatible with Ku-Band requirements. (Note: DME is an independent function on a separate frequency and is not a part of this format.)

THE SIGNAL FORMAT IS DESIGNED TO ALLOW A MAXIMUM DEGREE OF FLEXIBILITY. Functions can be transmitted in any order or combination to meet the unique operational needs of each site. This flexibility is made possible by a function preamble identification message. This message sets the airborne receiver to measure the angle or decode the data function that will follow. The ordering or timing of transmissions, therefore, is not important. This flexibility permits individual functions to be added or deleted to meet specific airport requirements. It also permits any TRSB airborne receiver to operate with any ground system. The only requirements are that a minimum data rate (minimum number of to-fro time-difference measurements per second) be maintained for each angle function, and that these measurements be relatively evenly distributed in time. An example of two 64-millisecond sequences of a configuration that utilizes all available functions is illustrated below.

THE TRSB FORMAT PROVIDES FOR CURRENT AND ANTICIPATED FUTURE REQUIREMENTS. Included are

- Proportional azimuth angle guidance to ±60° relative to runway centerline at a 13.5-Hz update rate (that is, data are renewed 13.5 times each second.)
- Proportional missed-approach azimuth guidance to ±40° relative to runway centerline at a 6.75-Hz update rate
- Proportional elevation guidance up to 30° with a 40.5-Hz update rate
- Flare guidance up to 15° with a 40.5-Hz update rate
- 360° azimuth guidance with a 6.75-Hz update rate
- Missed-approach or departure elevation function with a 6.75-Hz update rate
- Basic data prior to each angle function (includes function identification, airport identification, azimuth scale factors, and nominal and/or minimum selectable glide slope)
- Auxiliary data (for example, environmental and airport conditions)
- Facility status data
- Ground test signals
- Available time for other data and/or additional future functions.

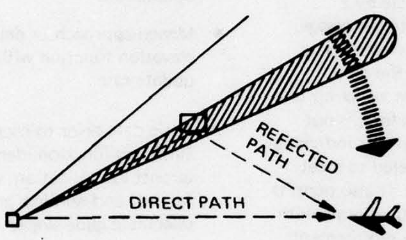


The TRSB signal offers maximum flexibility to meet unique user requirements

TRSB OPERATES EFFECTIVELY IN SEVERE MULTIPATH ENVIRONMENTS. TRSB offers several unique solutions to the multipath problem that has limited the implementation of other landing systems.

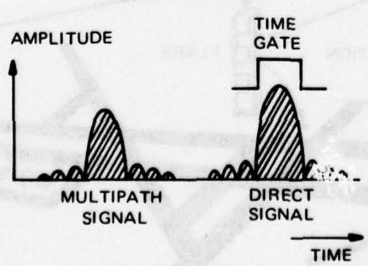
THERE ARE TWO TYPES OF MULTI-PATH. Multipath occurs when a microwave signal is reflected from a surface, such as an airport structure, a vehicle, and certain types of terrain. The resulting reflected beam is classified as either out-of-beam multipath or in-beam multipath, depending on its time of arrival in the aircraft receiver relative to the direct signal.

REFLECTED SIGNALS



OUT-OF-BEAM MULTIPATH. If the angle and therefore the time between the reflected and direct beam are relatively large, the aircraft receiver is subjected to out-of-beam multipath. In this case, the TRSB processor automatically rejects the reflected signal by placing a time gate, as illustrated below, around the desired guidance signal. This ensures that the correct signal is tracked even if the multipath signal amplitude momentarily exceeds that of the desired signal.

TIME GATING



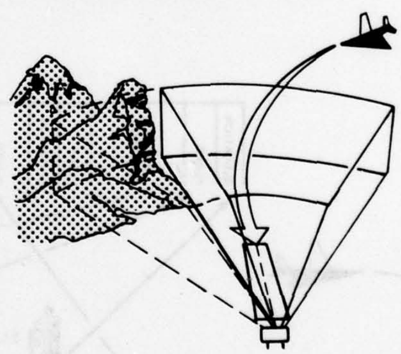
Time gating ensures that the correct signal is tracked, not the reflected one

IN-BEAM MULTIPATH. When the reflected and direct signals reach the aircraft almost simultaneously (the angle of arrival is very small), multipath is said to be in-beam. TRSB combats in-beam multipath by

- Shaping the horizontal pattern of the elevation antenna to reject lateral reflections
- Motion averaging, by utilizing the high data rates of TRSB
- Processing only the leading edge of the flare/elevation beam, which is not contaminated by the ground reflections.

COVERAGE CONTROL IS AVAILABLE TO ELIMINATE MULTIPATH AT EXTREMELY SEVERE PROBLEM SITES. Any MLS system will experience acquisition or tracking problems in those cases where the reflected signal is known to be persistent and greater in amplitude than the direct signal. A TRSB feature called coverage control can be implemented, at no cost, in such cases by simply programming the Beam Steering Unit (BSU). This feature permits a simple adjustment of the ground facility to limit the scan sector in the direction of the obstacle and thereby prevents acquisition of erroneous signals.

SELECTIVE COVERAGE CONTROL



By simple programming, the scan sector can be adjusted to prevent undesired obstacle reflections

TRSB IS A MODULAR SYSTEM WHICH CAN BE CONFIGURED TO MATCH THE NEEDS OF THE USER. A set of phased-array subsystems has been designed that may be installed in any combination to meet the broad range of user requirements.

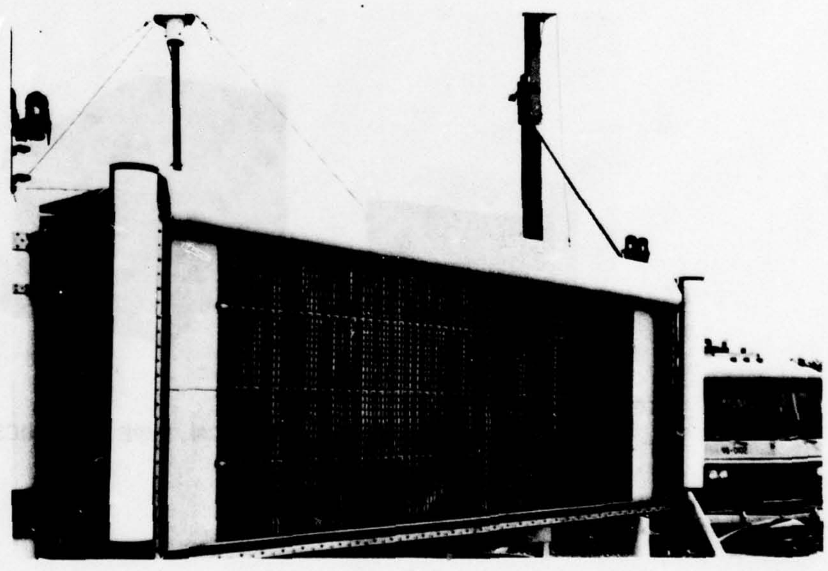
The minimum system configuration consists of approach azimuth and elevation subsystems. Flare, missed-approach, and range subsystems may be included or added later. Several antenna beamwidths are available, as indicated in the table below, from which a ground configuration can be designed to provide guidance signals-in-space of uniform quality in all airport environments.

NOTE: DME is an independent subsystem which is combined with appropriate azimuth and elevation subsystems to make up the total guidance system.

GROUND ANGLE SUBSYSTEMS

SUB-SYSTEM	NOMINAL BEAMWIDTH (DEGREES)	COVERAGE (DEGREES) *	PRINCIPAL APPLICATIONS
Azimuth	1	Up to ± 60	Approach Azimuth; Long Runways
Azimuth	2	Up to ± 60	Approach Azimuth; Intermediate Length Runways
Azimuth	3	Up to ± 60	Approach Azimuth; Short Runways Missed Approach Azimuth
Elevation	0.5	Up to 15	Flare
Elevation	1	Up to 30	Elevation (Severe multipath sites)**
Elevation	2	Up to 30	Elevation (Less severe multipath sites)**

* Coverage determined by Beam Steering Unit (BSU) for all arrays.
** See multipath discussion.



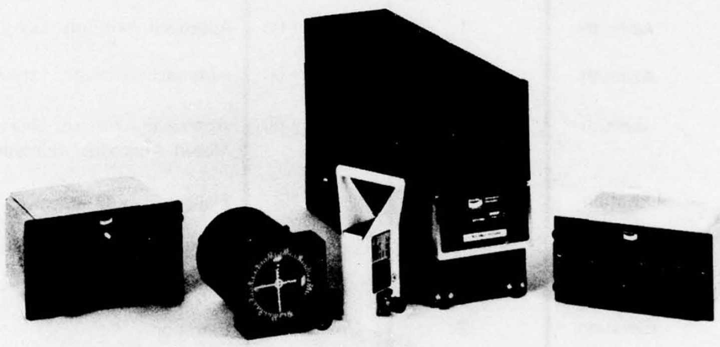
Phased Array Azimuth Antenna installed at the National Aviation Facilities Experimental Center. Radome is rolled back to expose radiating elements.

AIRBORNE RECEIVER DESIGNS ALSO STRESS THE MODULARITY CONCEPT. Users need only procure what is necessary for the services desired from any ground facility. To obtain approach and landing guidance at the lowest cost, an aircraft needs only an antenna and a basic receiver-processor unit operating with existing ILS displays. An air-transport category aircraft equipped for operation to low-weather minimums will carry redundant equipment and, in the future, advanced displays to fully utilize all of the inherent operational capabilities provided by TRSB.

The 200-channel TRSB angle receiver-processor provides angle information from the scanning beam azimuth and elevation subsystems and decodes the auxiliary data for display. Special monitoring ensures the integrity of the receiver output.

A second airborne unit is the DME. It is channeled to operate with the angle receiver-processor and provides a continual readout of distance.

Both the angle receiver-processor and the DME provide standard outputs to existing flight instruments and autopilot systems. An optional airborne computer would be used to generate curved or segmented approaches based on TRSB position information.



AIRLINE TYPE AVIONICS

GENERAL AVIATION TYPE AVIONICS

TRSB CAN PROVIDE ALL-WEATHER LANDING CAPABILITY AT MANY RUNWAYS THAT PRESENTLY DO NOT OFFER THIS SERVICE. This is made possible by

- The proposed channel plan, which contains enough channels for any foreseeable implementation
- High system integrity and precision
- Minimum siting requirements.

THE LARGE COVERAGE VOLUME PROVIDES FLIGHT PATH FLEXIBILITY. Transition from en route navigation is enhanced through the wide proportional coverage of MLS. Such flexibility in approach paths, coupled with high-quality guidance, can be used to achieve

- Improvements in runway and airport arrival capacity
- Better control of noise exposure near airports
- Optimized approach paths for future V/STOL aircraft
- Intercept of glide path and of runway centerline extended without overshoot
- Lower minimums at certain existing airports by providing precise missed-approach guidance
- Wake vortex avoidance flight paths.

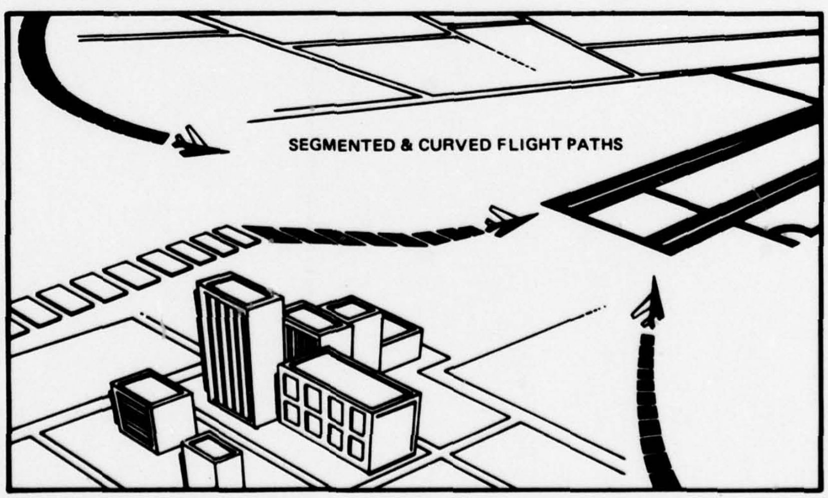
THE TRSB SIGNAL FORMAT ENSURES THAT EVERY AIRBORNE USER MAY RECEIVE LANDING GUIDANCE FROM EVERY GROUND INSTALLATION. Compatibility is ensured between facilities serving international civil aviation and those serving unique national requirements.

TRSB SPANS THE ENTIRE RANGE OF APPROACH AND LANDING OPERATIONS FOR ALL AIRCRAFT TYPES. This includes CTOL, STOL, and VTOL aircraft operating over a wide range of flight profiles. The particular needs of users, ranging from general aviation to major air carriers, are accommodated. TRSB is adaptable to special military applications, such as transportable or shipboard configurations on a compatible basis with civil systems.

HIGH RELIABILITY, INTEGRITY, AND SAFETY OF TRSB ARE ENHANCED BY SEVERAL IMPORTANT FEATURES. These include

- Simple TRSB receiver processing
- Multipath immunity features on the ground and in the airborne receiver-processor
- A comprehensive monitoring system that verifies the status of all subsystems and the radiated signal. Status data are transmitted to all aircraft six times each second.
- Coding features, such as parity and symmetry checks, that prevent the mixing of functions.

TRSB PROVIDES CATEGORY-III QUALITY GUIDANCE. TRSB signal guidance quality has already been proved via demonstration of fully automatic landings, including rollout, in a current commercial transport aircraft (Boeing 737) and an executive jet (North American Sabreliner).



TRSB provides precision guidance for curved and segmented approaches for noise abatement and traffic separation, as well as for autoland and rollout

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